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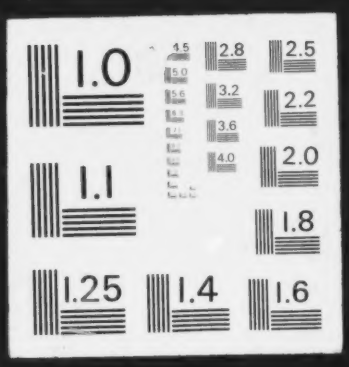

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Applying Fabric Filtration to Refuse-Fired Boilers A Pilot-Scale Investigation

Nashville Thermal Transfer Corp, Tenn

Prepared for

Industrial Environmental Research Lab, Research Triangle Park, N C

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EPA U.S. Environmental Protection Agency
Office of Research and Development
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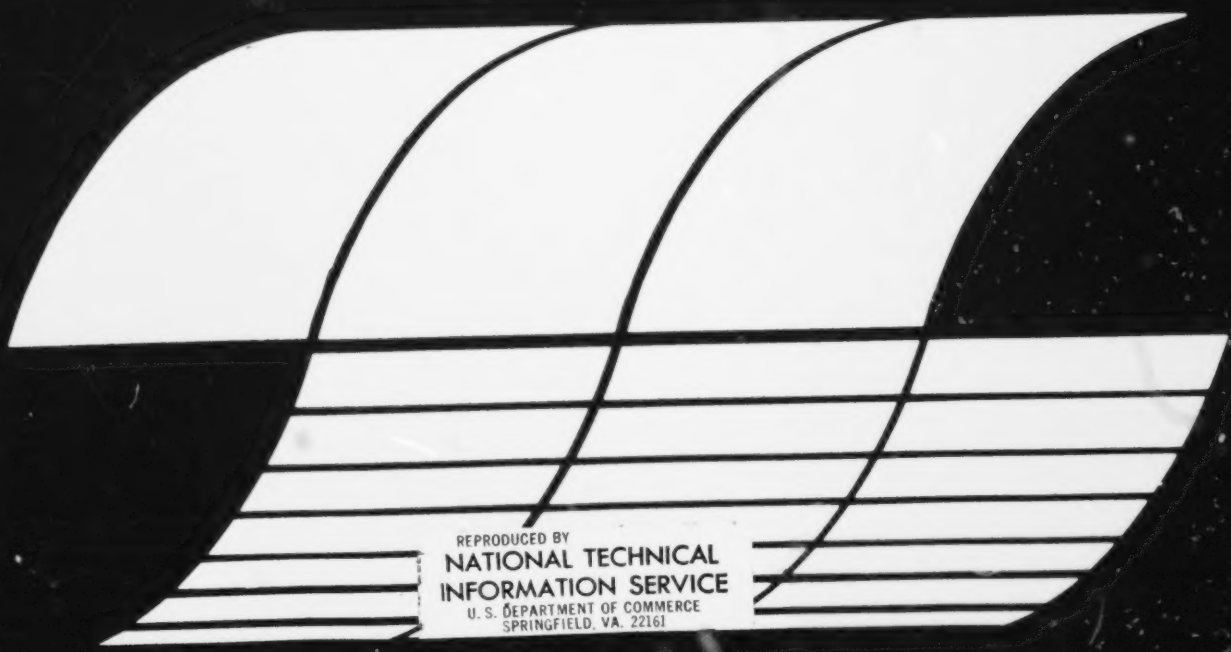
APPLYING FABRIC FILTRATION TO REFUSE-FIRED BOILERS: A PILOT-SCALE INVESTIGATION

Interagency
Energy-Environment
Research and Development
Program Report



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16. ABSTRACT
The report gives results of a pilot-scale investigation to determine the techno-economic feasibility of applying fabric filter dust collectors to solid refuse fired boilers. The pilot facility, installed on a slipstream of a 135,000 lb/hr boiler, was sized to handle 9000 acfm at an apparent filtering velocity of 6 fpm. Filter media evaluated included a woven glass, a felted glass, and a PTFE laminate on a woven backing. The three filter media had overall efficiencies greater than 99.8%, at apparent filtering velocities of 6 fpm or less, with an inlet loading of 0.5 gr/dscf. For the brief exposures during performance testing, none of the bag materials showed an wear problems. Installed costs for a woven glass fabric filter (the least expensive material tested) capable of handling 140,000 acfm were $317,000, $422,000 and $817,000 ($2.26, $3.01, and $5.83/acfm, respectively) at corresponding air-to-cloth ratios of 8.9, 5.8, and 2.9. Installed, operating, and annualized costs for other filter media, as well as costs for electrostatic precipitation and wet scrubbing, are also presented.

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Dust Collectors		Stationary Sources	13A, 11I
Dust	Fabric Laminates	Particulate	11G, 11D
Fabrics	Boilers	Fabric Filters	11E
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APPLYING FABRIC FILTRATION TO REFUSE-FIRED BOILERS: A PILOT-SCALE INVESTIGATION

by

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12

ABSTRACT

A pilot scale investigation was conducted to determine the techno-economic feasibility of applying fabric filter dust collectors to solid refuse fired boilers. The pilot facility, installed on a slip stream of a 135,000 lb./hr. boiler, was sized to handle 9,000 ACFM at an apparent filtering velocity of 6 fpm. Filter media evaluated included a woven glass, a felted glass and a PTFE laminate on a woven backing.

Overall efficiencies greater than 99.8% were achieved with all three types of filter media tested when operating at apparent filtering velocities of 6 fpm or less and having an inlet loading of 0.5 gr/DSCF. For the brief exposure period encountered during the performance testing, none of the bag materials tested showed any wear problems.

Installed costs for a fabric filter capable of handling 140,000 ACFM and employing woven glass, the least expensive material tested, were determined to be $317,000, $422,000 and $817,000 or $2.26/ACFM, $3.01/ACFM and $5.83/ACFM respectively at corresponding air-to-cloth ratios of 8.9, 5.8 and 2.9. Installed, operating and annualized costs for other filter media as well as costs for electrostatic precipitation and wet scrubbing are also presented.

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The two pilot fabric filter dust collectors were supplied to the program by EssTee Manufacturing, Inc. and Enviro-Systems & Research, Inc.

Test bags of three filter media types were donated to the program by the following companies:

Globe Albany Filtration
W. L. Gore and Associates, Inc.
Huyck Corporation

Test filter media test swatches were provided by:

E. I. du Pont de Nemours & Company, Inc.

Statistical analysis was performed by Dr. Ray Meyers of Virginia Polytechnic Institute.

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INTRODUCTION

The purpose of this study was to provide a preliminary technical and economic analysis of the feasibility of applying fabric filter dust collectors to refuse fired boilers. A program with some of the same objectives had been initiated at NTTC under NTTC sponsorship and with technical program management by Sanders & Thomas, Inc. (Unit of STV, Inc.), an engineering firm with offices in Nashville, Tennessee.

After two pilot facilities had been installed and briefly operated at the NTTC facility, this initial program was aborted due to a number of considerations, including funding difficulties.

At this point EPA sponsorship was obtained with the prime contractor being NTTC and the major subcontractor, responsible for technical program management and execution, being Enviro-Systems & Research, Inc. After careful consideration of the funds available and in recognition that the program could not immediately provide both long-term life data and performance data, it was decided to first perform filter media screening on the basis of short-term performance test, primarily dust removal efficiencies. It was anticipated that filter media life studies and long-term life studies would be the basis for a subsequent program if the initial program indicated satisfactory short-term results.

CONCLUSIONS

The three filter media tested for dust removal capability indicated high level removal over a range of air-to-cloth ratios (apparent filtration velocity).

For air-to-cloth ratios of approximately 3 to 1 and 6 to 1 the experimental felted glass media showed the lowest outlet dust concentration and the woven glass media the highest. The performance of even the woven glass media was considered more than satisfactory to meet present code requirements for this application.

No clear correlation between filtration velocity and outlet dust concentration was demonstrated. There may well be such a correlation; however, testing circumstances did not allow for determination of it in this program.

The three filter media tested for dust removal capability did not show signs of wear or weakening during this test program. It should be noted, however, that total on-stream time was very limited.

The pressure drops obtained for the three filter media performance-tested were within the commercially acceptable range. It is believed that pressure drops obtained were influenced by the sub-dew point operation of the pilot unit, thus the pressure drops reported may have been higher than those a short-term, above dew point operation would provide

No comparison of one filter media with another in terms of pressure drop is made because of the suspected dew point influence.

The economic analysis indicates that the wet scrubber has both higher operating and annualized costs than either the ESP or fabric

filter. In view of this and considering the potential corrosion problems associated with any wet dust collection method employed in this application, it appears that wet scrubbing is the least suitable of the three alternatives.

The economic analysis also indicates that annualized costs of the ESP and fabric filter are very close for many of the cases considered. This being the case, the need to replace bag life and pressure drop assumptions with empirical facts is necessary for final selection of the best alternative.

RECOMMENDATIONS

This pilot scale study has indicated that at high filtering velocities (6 fpm or greater) it is possible to achieve high level of dust removal efficiencies. The economic analysis indicates that, for the bag life and pressure drop assumptions made and for present federal standards, fabric filtration can be competitive with electrostatic precipitation and that these two methods are a better economic alternative than scrubbing. The primary limitation of this program is that it did not provide any life data for the filter media studied and in addition, due to the existing pilot plant system, did not provide correlations of air-to-cloth ratio and pressure drop.

In view of the favorable performance results obtained to date, and in light of the competitive economics which are possible as well as possible future lowering of allowable emission levels, a follow-up program is proposed. It is recommended that the pilot plant be refurbished to insure higher temperature (above dew point) operation. Once this has been accomplished it is recommended that the pilot plant be brought on stream and operated on a twenty-four hour basis for a period of one year. Implementation of the above should provide a meaningful indicator of bag life and allow for long term performance testing. Periodic (intermittant) evaluation of both pressure drop and dust removal performance is recommended as the heart of this life study.

PROGRAM DESCRIPTION

Introduction

A test program was conducted on an existing fabric filter (baghouse) system that was installed on the slip-stream of a refuse-fired boiler owned and operated by the Nashville Thermal Transfer Corporation (NTTC), a public authority of the State of Tennessee. By burning approximately 25% of the city's daily output of refuse, this plant can supply steam and chilled water to twenty-nine downtown buildings, including the State Capitol.

An experimental program was conducted by NTTC in 1975 for the purpose of establishing methods of controlling pollution from refuse-fired boilers. Enviro-Systems & Research was selected to participate in this program and provided NTTC with a two module Enviro-Clean RA-1 rectangular dust collector to be used as a vehicle for filter media screening. A second baghouse, an EssTee pulse jet type, was also tested. Only a very preliminary screening of filter media was included in the original program.

The first program was terminated due to monetary considerations, but data obtained indicated that a fabric filter dust collector was capable of achieving excellent dust collection efficiencies, therefore, this program was instituted to confirm and to validate this data.

Purpose and Objectives

This study was initiated to evaluate the applicability of fabric filtration as a viable alternative for fly ash control on a refuse-fired boiler.

In order to complete an effective evaluation, the program needed these objectives:

1. Techno-economic screening of three (3) types of filter media.
2. Determination of both the mass and fractional efficiency of the three types of filter media tested.
3. Development of a family of curves of pressure drop across the bags vs. air-to-cloth ratio for three (3) types of filter media.
4. Techno-economic comparison of the three (3) filter media and alternate fly ash control methods; e.g., electrostatic precipitators and wet scrubbers.
5. Comparison of the pulse jet and hybrid reverse-air baghouses with respect to filter cleaning efficiencies.
6. Recommendations of candidate filter media that should be employed in a follow-up life study program.
7. Recommendation of a follow-up life program.

Pilot Plant Description

One pilot plant was a two module Enviro-Clean RA-1 rectangular dust collector. The model number is 144-RA1-5-104 and the dimensions are provided in the accompanying drawing RA-1000-0 (See Figure 1). This plant consists of twelve (12) cells, each cell having twelve (12) bags. The bags are five (5) inches in diameter and eight (8) feet eight (8) inches long. The total cloth area is approximately 1,660 square feet.

The operation of the baghouse is as follows: The dirty gases enter one end of the unit, pass through the tapered duct, into the classifier, then through the bags. The classifier forces the dirty gases to change direction 90°, then 180°. This quick directional

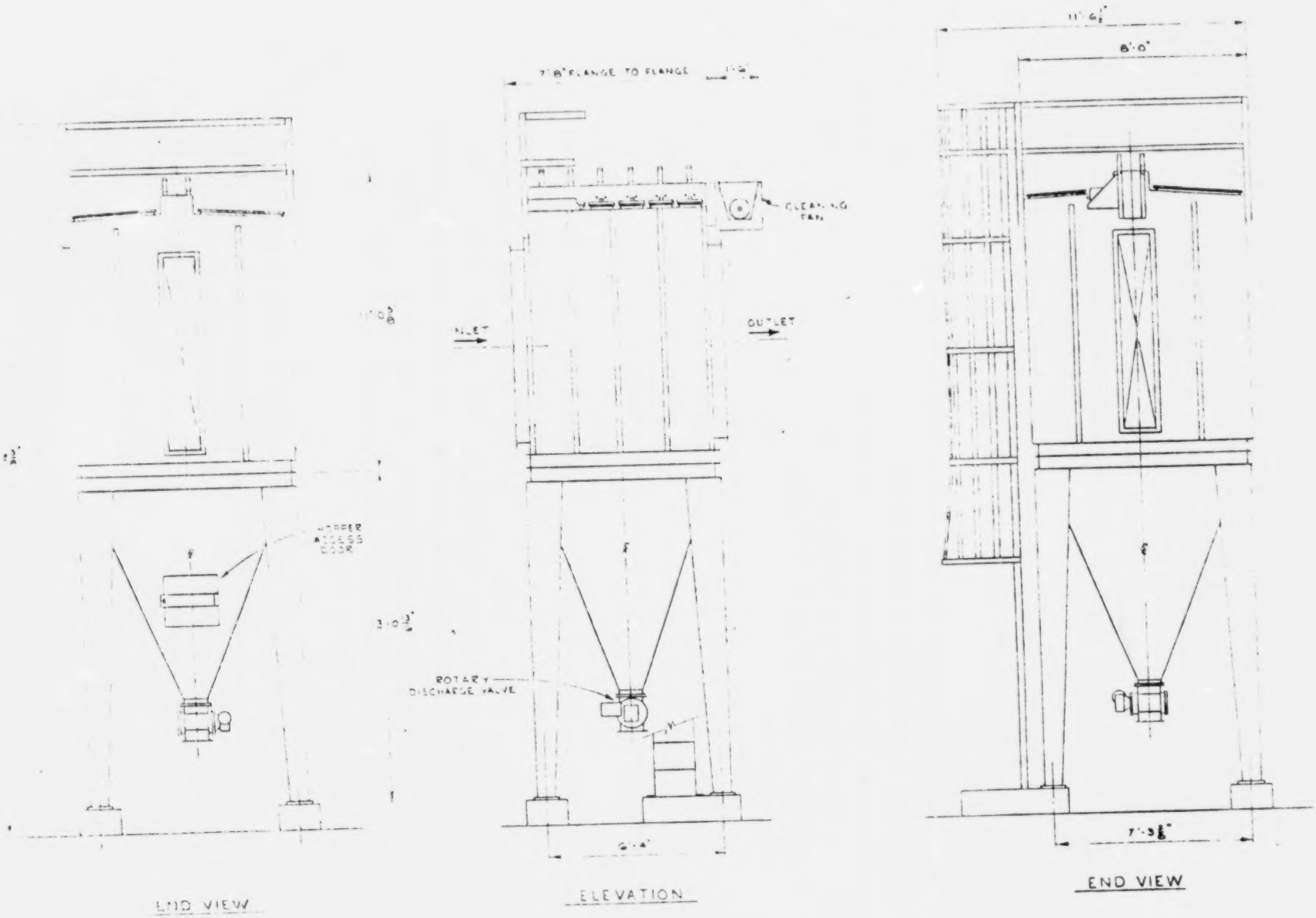

Figure 1. Schematic diagram of the Enviro-Clean RA-1 dust collector model 144RA1-5-104.

change forces the larger and heavier particles out of the flow so that they will fall directly into the hopper. Dirty gases enter the classifier through a central duct tapered to feed the same quantity of gas into each cell. The gases are forced through the fabric filter into the center of the bags. The cleaned gases are drawn up and out through the center of the filtering bag into a center exit plenum via an open damper in the cell above the tube sheet (to which the bags are locked on top and bottom via snap rings).

As solid matter collects on the outside of the filter bag, it builds a cake or crust which begins to restrict the flow of gases. The bags are cleaned one cell at a time by closing off the cell damper to the exit plenum and at the same time opening the pneumatic damper. Clean air enters through the damper, is forced down the filter bag (opposite the normal flow direction), and expands the bag with such a shock that the "cake" is cracked and particulate matter falls off the bag and into the hopper. Damper system and control panel arrangements allow for variations in main gas volume, reverse-air volume, duration of cleaning and frequency of cleaning.

The second pilot plant was an EssTee pulse air jet type model number ST12-48. It is an automatic continuous dust collector utilizing a venturi-type orifice and injector for compressed air cleaning of collected particulates from the outside of the filter fabric. The plant housed forty-eight (48) bags, each six and one-half (6½) inches in diameter, twelve (12) feet three (3) inches long. The bags were cageless and in a quantity sufficient for an 8 to 1 air-to-cloth ratio.

The cleaning cycle is controlled by an adjustable timer that ranges from 0.1 second to two seconds and intervals between cleaning from four to thirty seconds. The pressure of the compressed air cleaning is approximately forty (40) p.s.i.

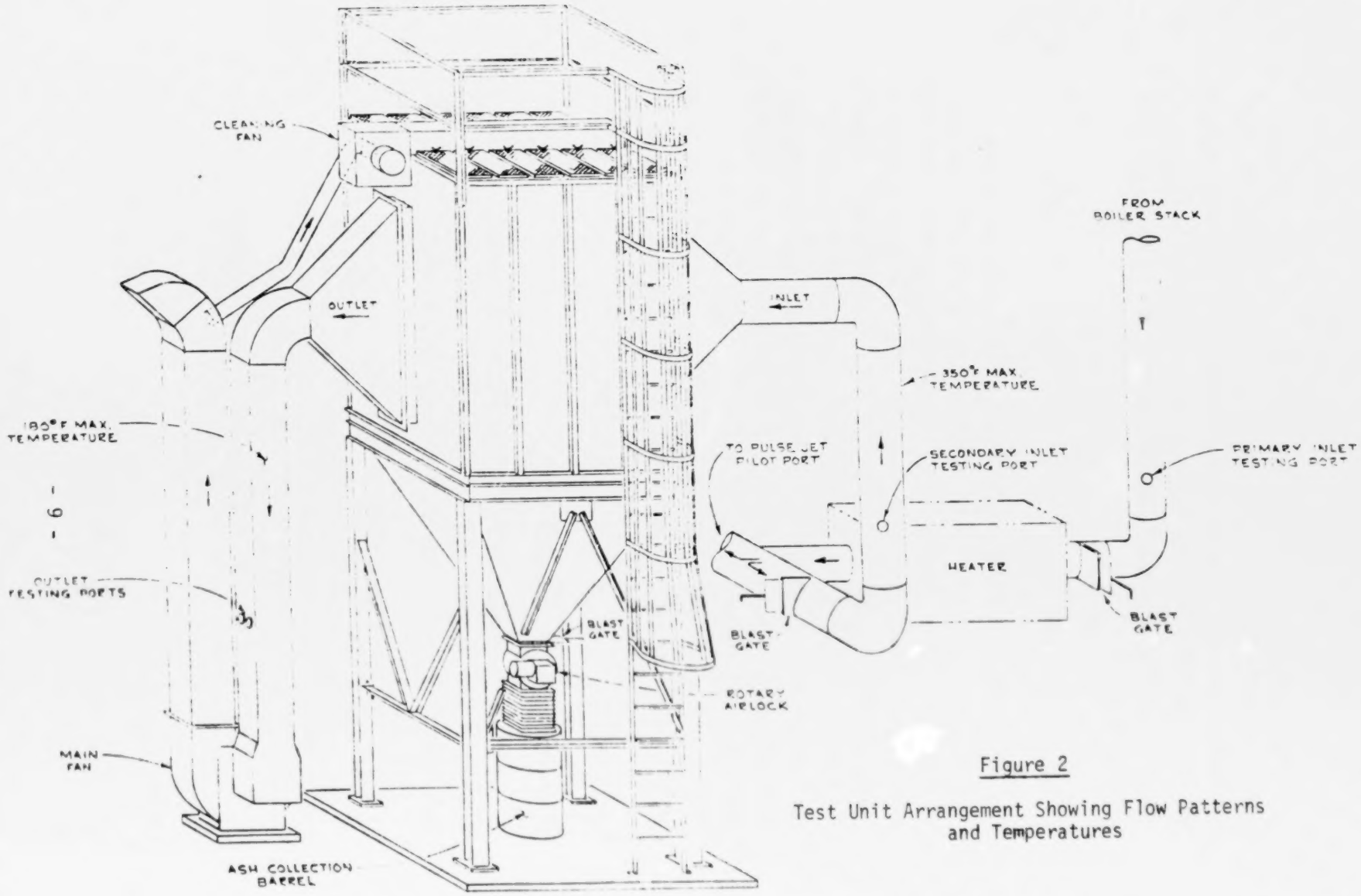

Figure 2

Test Unit Arrangement Showing Flow Patterns and Temperatures

The EssTee baghouse is an insulated, all welded structure of prefabricated sections to give single compartment operation. The EssTee baghouse was intended to test woven glass bags for comparison with the Enviro-Systems & Research system, but difficulties faced in getting the EssTee baghouse operational in time made this impossible.

Filter Media

Three types of filters were donated for use in this study. Gore Associates provided forty (40) Gore-Tex bags of PTFE laminate on a woven backing, Huyck Research Center donated twenty-eight (28) experimental felted glass fabric bags, and Globe Albany supplied forty (40) woven glass (22½ oz.) bags with the Q78 finish. Globe Albany later agreed to provide enough of the same bags to outfit the EssTee baghouse. Since there were not enough bags to entirely fill the Enviro-Systems baghouse, the unused cells were blocked off and inlet gas volumes adjusted accordingly. Swatches of German Nomex, Teflon felt, and Teflon woven fabrics were also placed in the baghouse for wear comparison. Appendix A-1 lists data for each fabric -- both new and exposed at NTTC.

Description of the NTTC Boilers

NTTC operates two (2) multi-pass boilers designed by Babcock and Wilcox Company and keeps a Combustion Engineering Company fossil fuel fired boiler as a stand-by. As described by NTTC:

> ...The multi-pass boiler is a welded membrane water-wall design with an integral economizer. The water wall design makes possible the gas-tight construction, eliminating the problem of corrosion between the tubes and the outer casing. The furnace area has a coating of silicone carbide on the tubes, thereby reducing erosion and corrosion in the burning area.

Continuous boiler operation is made possible by cleaning the in-line convector tubes with an automatic soot blower. Normal continuous capacity is 109,000 lb./hr. Steam pressure delivered at the super-heater outlet is 400 psig. Total design efficiency of the furnace and boiler is 67.5%, and the combustion efficiency of the grate is 95.5%.

Installation at NTTC

The pilot plant was originally installed on one of the NTTC boilers in September 1975. The slip stream is a 16 inch duct approximately 250 feet long with numerous turns. The duct is covered with 1½ inch metal-skinned insulation to decrease heat loss. The outlet and reverse-air ducts were also insulated. A temperature profile (Figure 2) shows a maximum temperature of 350° F in the inlet duct while the maximum at the outlet was 180° F. Figure 3 is a photograph of the plant.

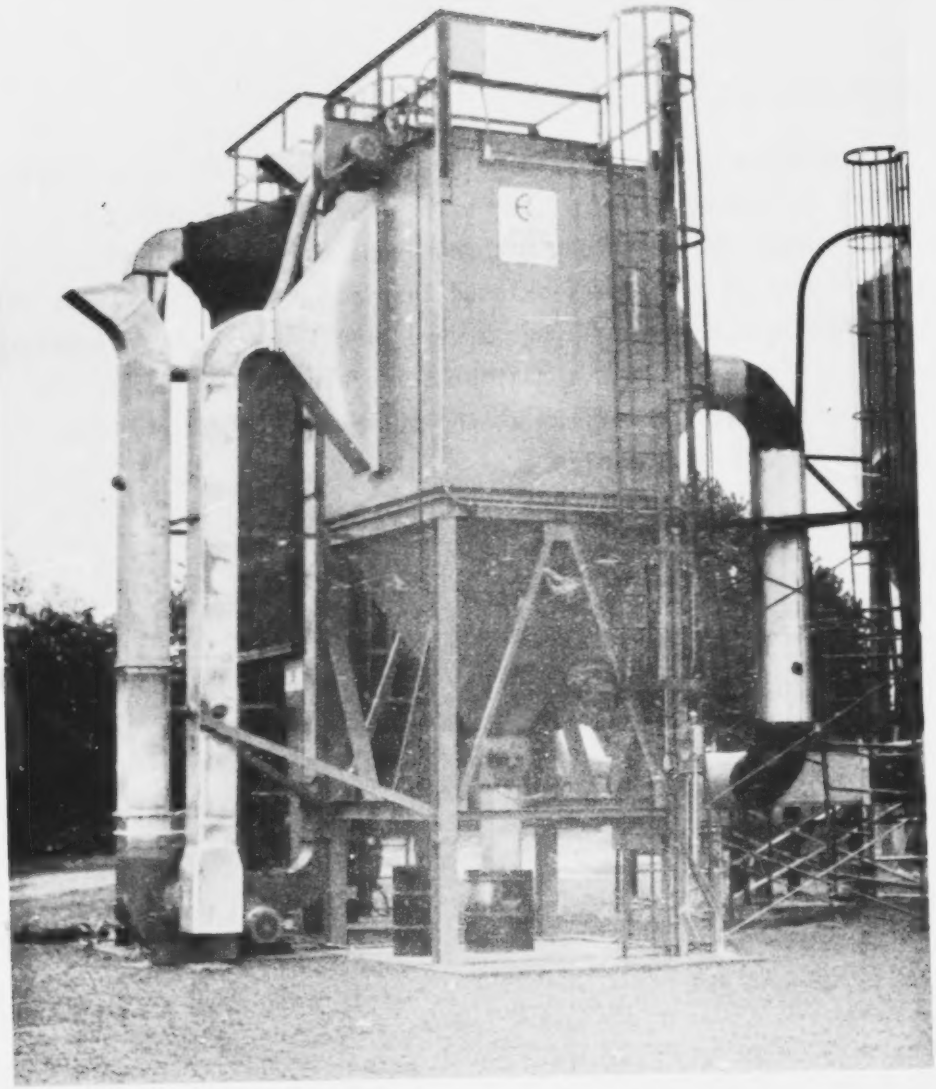

Figure 3

Fabric Filter Pilot Plant
Installed at Nashville Thermal Transfer Corp.

TEST METHODS

The intent of this section is to describe the test methods employed and the operating procedures followed in obtaining the data. It is assumed that the reader is familiar with the accepted EPA test methods, therefore the procedures for these are not elaborated.

Velocity

Velocity traverses, performed with a Stausscheibe pitot tube and inclined draft gauge, were conducted in general accordance with EPA Method 2 for determining inlet and outlet volumetric flow rates.

Particulates

Particulate concentration measurements were conducted in general accordance with Method 5 described in the Code of Federal Regulations, Volume 36, Number 247. Only the "Dry Filterable Catch" (material collected by the filter and apparatus preceding the filter) is reported.

The sampling train consisted of a stainless steel nozzle, stainless steel probe, heated Fiberglas filter, impingers for moisture determinations, vacuum source and dry gas meter.

Velocities and temperatures were monitored simultaneously with the sample extraction.

Particle size analysis was performed with an Andersen in-situ particle size analyzer. Use of the Andersen inertial impactor followed the procedures recommended in "Guidelines to Conduct Fractional Efficiency Evaluations of Particulate Control Systems", prepared

April 1974, by the Process Measurements Section of the Control Systems Laboratory of EPA at Research Triangle Park, North Carolina. Since this guideline necessarily allows for certain options in Andersen methodology, the procedures utilized are given below:

1. One sample was conducted for each test. All sampling was in-situ.
2. Special glass fiber impaction stage substrates and a 2½ inch diameter glass fiber substrate as a back-up filter were employed.
3. The impactor was oriented horizontally inside both the inlet duct and the outlet stack during sampling.
4. The impactor was heated by means of electrical heat tape and a thermocouple feedback temperature controller. Gas exiting the impactor was maintained at a temperature of 250° F or 20° F above the stack temperature, whichever was greater.
5. No precutter was used.
6. Flow rate through the impactor was adjusted so as not to exceed the critical velocity for the last stage.
7. Outlet sample time varied from 1 to 2 hours, depending on the rate of loading - a function of the media and A/C ratio being tested.
8. Sampling time was designed to avoid overloading any single stage.
9. Sampling rates were maintained as close to isokinetic conditions as possible without exceeding recommended stage velocities.
10. All substrate weighings were accomplished on a Type H54AR Mettler analytical balance which has a sensitivity of 0.01 milligrams. Substrates were oven dried and dessicated prior to weighing.

The Andersen impactor has been calibrated by several independent laboratories to arrive at the current respective size cuts for each stage. The calibrations were referenced to unit density (1g/cc), spherical particles so that the aerodynamically equivalent sized particles collected on each stage are always identical for any given flow rate. Therefore, a stack sample containing a mixture of shapes and densities is fractionated and collected according to its aerodynamic characteristics and is aerodynamically equivalent in size to the unit density spheres collected on each specific stage during calibration. The effective aerodynamic diameter at 70° F is determined for each Andersen sample based on the flow rate through the impactor. A correction factor for determining the physical diameter of spherical particles having other than unit density must be used. This correction factor yields the effective aerodynamic diameter for a specific density. Also a correction factor is used for determining the effective aerodynamic diameter for elevated temperatures.

All particle sizes presented were corrected for gas temperature, using correction factor curves supplied by the impactor manufacturer.

Permeability

Permeability tests on the fabrics employed were performed on a Frazier air permeability instrument. All testing was conducted in accordance with the manufacturer's specifications.

SO_2 - SO_3

EPA Method 8 was employed for determination of SO_2 and sulfuric acid mist concentration in the inlet to the baghouse. Sulfuric acid mist and SO_3 were reported together as SO_3.

Fluoride

The specific ion electrode method was utilized in determining fluoride ion concentration at the baghouse inlet. This method

is described in the Orion Research Bulletin (Fluoride electrode).

Chloride

The Mercuric Nitrate Titration Method, as described in the 13th Edition of Standard Methods, Pages 97-99, was used in the determination of chloride ion concentration.

DATA OBTAINED

Inlet Conditions

An inlet profile was made at the beginning of the NTTC project and again in November during the first testing of the experimental felted glass fabric. Tables 1 and 2 list these results. Analyses of samples taken in August 1976 and March 1977 indicate that the chloride ion concentrations can range between 53.2 ppm and 193.3 ppm. Fluoride concentrations ranged between 0.17 ppm and 0.50 ppm. The high chloride and fluoride concentrations could result in increased bag deterioration with longer on-stream times if gas temperatures could not be kept high enough. There was, however, no evidence of this in the testing periods used. Ash analyses can be found in Appendix A-2

Due partly to the low flow rates needed to accommodate so few bags, great difficulty was encountered in obtaining Brinks cascade impactor data. Inlet particle size data for two tests can be viewed in Figure 4 and are listed in Appendix A-4. Inlet grain loadings for Brinks Runs 1 and 2 are 1.29964 grains/DSCF and 1.63005 grains/DSCF. In March of 1977 (during actual bag testing) inlet grain loadings were again measured, this time by EPA Method 5 procedures. The grain loadings were 0.538 grains/DSCF at the existing inlet port and 0.329 grains/DSCF at the port installed by Enviro-Systems & Research nearer the baghouses. It appears that particulate in the gas stream dropped out in ductwork between the two ports. For mass efficiency calculations, particulate concentrations from the original inlet port will be used although efficiencies would not vary by much if the new inlet port data were used.

Table 1

Nashville Thermal Transfer

Baghouse Inlet Gas Stream Profile

July, 1976

Test Data	Run Number 1	2	3
Date	7/29/76	7/30/76	7/30/76
Gas Temperature (avg. °F)	411	443	410
Stack Rate (SCFMD)	1583	1581	1520
Flue Gas Composition			
H_2O (%)	15.94	16.03	18.68
O_2 (%)	7.1	7.1	7.1
CO (%)	-	-	-
CO_2 (%)	12.9	12.9	12.9
Particulate Concentration (Grains/SCFD)	0.72	1.38	1.76
Isokinetic Rate (%)	109.16	109.3	94.3
Cl^- (ppm)	84.1	83.7	68.04
F^- (ppm)	7.09	0.8	0.61

Table 2

Inlet Emission Profile

Date	11/20/76
Stack Temp. (Avg. ^{o}F)	360^{o}F
Stack Rate (SCFMD)	2252.2
Stack Rate (ACFM)	3826.6
Flue Gas Composition	
H_2O (%)	7%
O_2 (%)	10.88 %
CO_2 (%)	7.25 %
Metered Gas Volume (SCFD)	21.90
Particulate Concentration (Grains/SCFD)	1.1634
Emission Rates (lb/Hr)	22.46
Isokinetic Rate (%)	101.2%

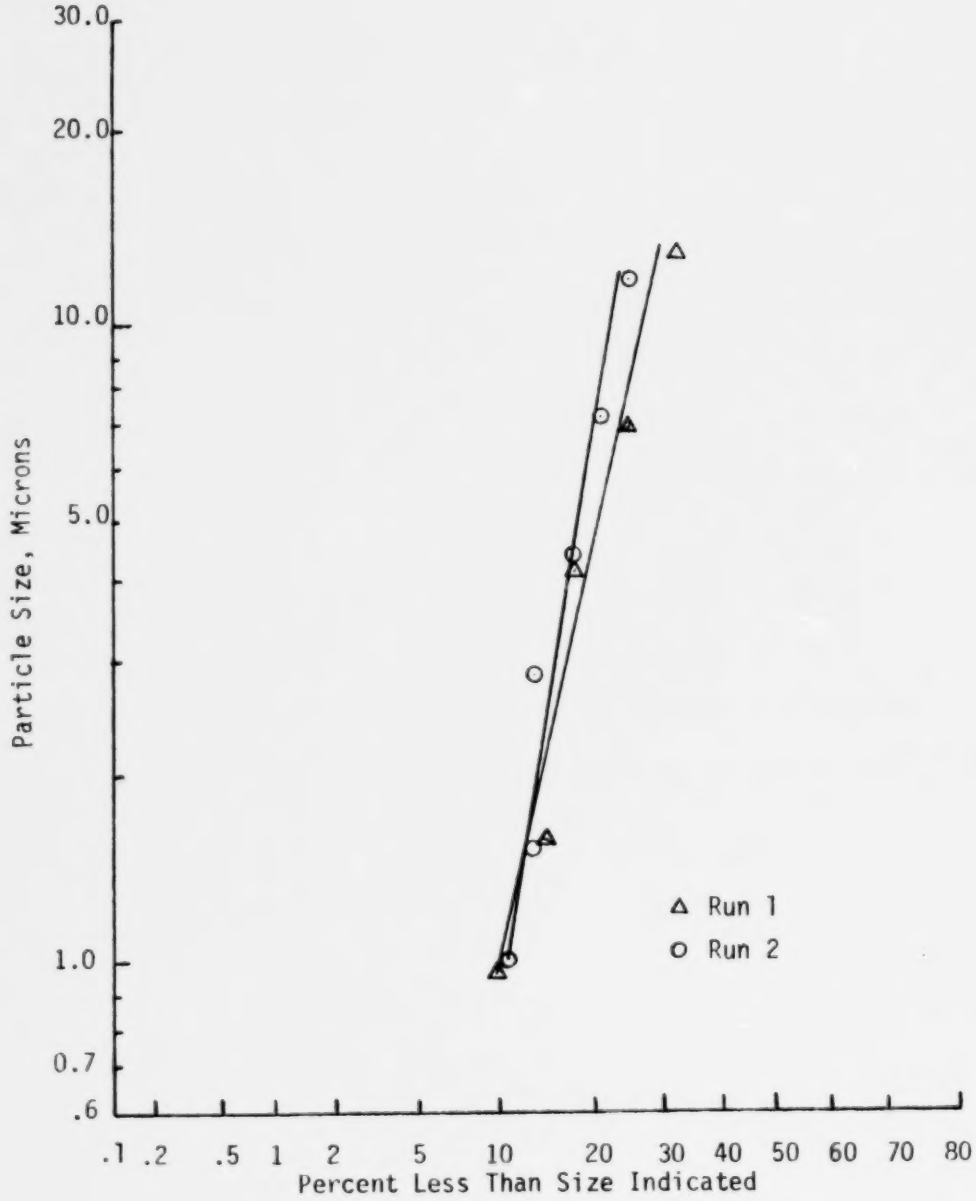

Figure 4

Inlet Particle Size Distribution for Two Brinks Impactor Runs (3/22/77)

Substrate Conditioning

Before Andersen sampling could be conducted, both Gelman and Reeve Angel (934-AH) filters had to be tested for applicability for use in this type of gas stream. Results of the conditioning can be found in Table 3.

Conclusions reached by reviewing these data are:

1. Gelman substrates showed inconsistent behavior; i.e., a modest weight loss on the first conditioning (Line 1) and a large weight gain on the second conditioning (Line 7), despite the fact that the two (2) conditioning periods were similar. There is no data concerning the gas stream itself.
2. Gelman back-up filters showed an inexplicably large weight gain (Lines 2 & 4), possibly indicating a filter type capable of reacting chemically with the gas stream.
3. Based on the limited data obtained (three (3) sets conditioned), Reeve Angel substrates seemed to be the superior filter when compared with Gelman. Weight changes were very modest (less than Gelman) and there was a much lower variability between stages in a set. This is in complete agreement with literature results.

Data not shown here indicate that errors classed as "possibly unavoidable" (i.e., errors in loading and unloading substrates and at the balance place) are on the order of 0.05 mg.

Permeabilities

Permeability tests were performed on three new bags of each type tested. The results are listed in Table 4. These tests were

Table 3

Conditioning

SUBSTRATE TYPE	NUMBER OF SAMPLE SETS	TEMP. (°F)	TIME (HRS)	ACFM	AVG. NET CHANGE (mg)
1)GELMAN	16	430	2	0.5	-0.038 (S.D. = 0.075mg)
2)GELMAN (Back-up Filter)	16	430	2	0.5	2.52
3)GELMAN	3	160	2	0.5	0.057 + 0.01
4)GELMAN (Back-up Filter)	3	160	2	0.5	2.5
5)REEVE ANGEL 934-AH	3	160	2	0.5	0.023 + 0.01
6)REEVE ANGEL 934-AH (Back-up Filter)	3	160	2	0.5	0.067 + 0.02
7)GELMAN	2	160	2	0.5	0.13 + 0.07

Table 4

Permeability Tests
(New Bags)

Bag No.	Type	$\frac{ft.^3/min.}{ft.^2}$ Opp. Seam	Rt. of Seam	Lt. of Seam
1	Experimental Felted Glass	27.2	25.2	26.6
2	Experimental Felted Glass	23.0	20.8	21.3
3	Experimental Felted Glass	21.0	16.2	22.2
1	Woven Glass	27.5	21.5	27.7
2	Woven Glass	24.8	22.6	25.2
3	Woven Glass	21.3	22.0	24.0
1	PTFE Laminate	6.6	6.9	6.7
2	PTFE Laminate	9.4	12.3	10.3
3	PTFE Laminate	8.3	8.5	8.7

also made on swatches of each fabric placed in the baghouse. Permeability results after exposure (for bags and fabric swatches) are in Table 5.

It appears that of the three fabrics actually used, the experimental felted glass bags retain the most of their original permeabilities and woven glass the least.

Other test results for each fabric swatch can be found in Appendix A-1.

Experimental Felted Glass Fabric

Twenty-eight experimental felted glass bags were placed in the Enviro-Systems & Research baghouse as shown in Figure 5. These bags were used for two separate sets of tests -- one completed in November 1976 and the other in early April 1977. The bags were removed from the baghouse for cleaning between tests. Results for the November tests can be found in Appendix A-3. Permeability tests results listed in Table 6 shows that vacuum cleaning of bags restores permeability values nearly to those of the original bag.

Results: April, 1977

The experimental felted glass bags were placed in the same configuration as in the November tests, and is shown in Figure 5. Pressure drop vs. time curves can be seen in Figures 6 through 8 for the April tests.

A four hour test with no reverse-air cleaning was conducted to determine pressure drop across the house vs. air-to-cloth ratio. The results of this test can be seen graphically in Figure 9. There is a half inch difference in pressure drop between the beginning and end of the test at an air-to-cloth ratio of three (3). Also in the April test the pressure drop increases through the middle range of air-to-

Table 5

Permeability Comparison:

Fabric Exposed at NTTC

Fabric Type	Permeability After Exposure ($ft.^3/ft.^2/min.$)
German Nomex	17.9
Woven Glass	6.7
PTFE Laminate	3.7
Experimental Felted Glass	19.8
Teflon (Felt)	6.7
Teflon (Woven)	28.3

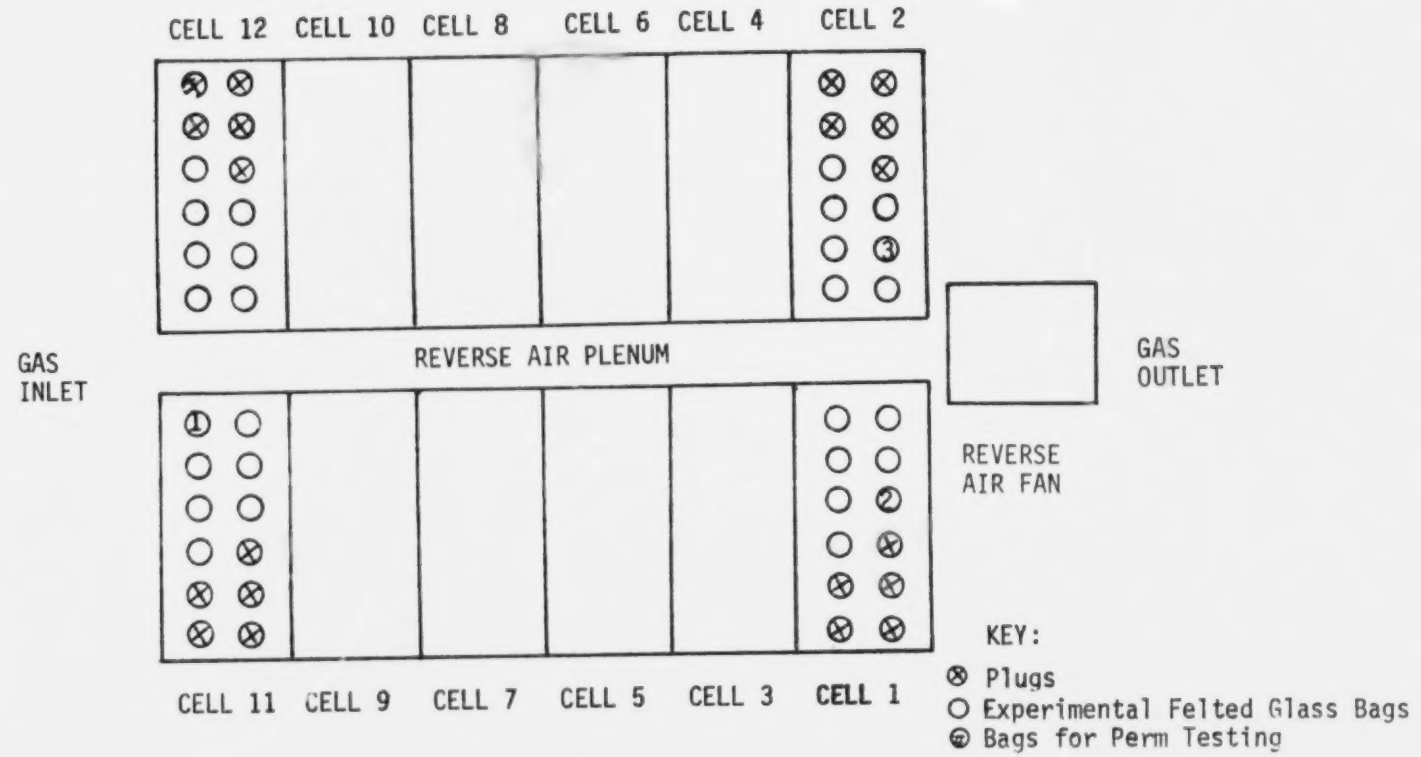

Figure 5

Experimental Felted Glass Bag Positioning
in Enviro-Systems Baghouse

Table 6

Permeability Tests

Felted Glass Bag Used During Testing Program at NTTC

Conditioning	Permeability CFM Air/Ft.^{2} Cloth		
	Opposite of Seam	Right of Seam	Left of Seam
Dirty	14.2	14.1	12.5
Vacuum Cleaned (High)	23.0	17.2	20.3
Machine Washed	26.9	26.4	24.2
Original Bag #2	23.0	20.8	21.3

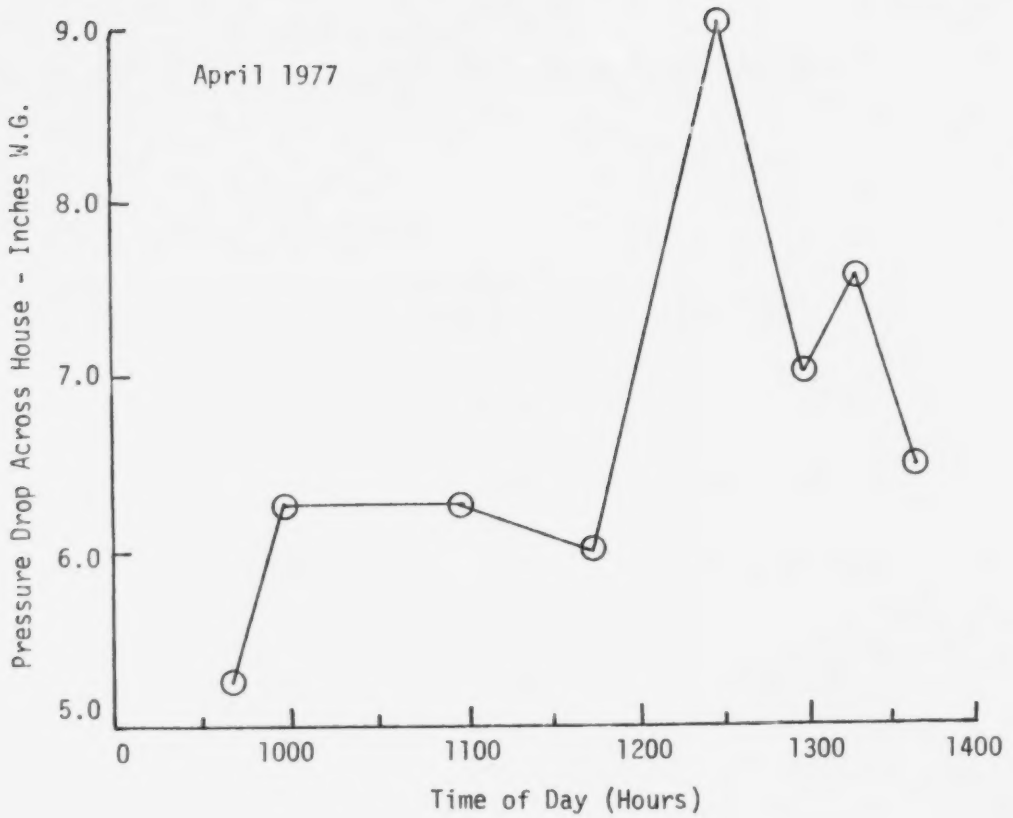

Figure 6

Pressure Drop (In Inches of Water) vs. Time for Experimental Felted Glass Bags with an A/C = 8.7 (No Reverse-Air Cleaning)

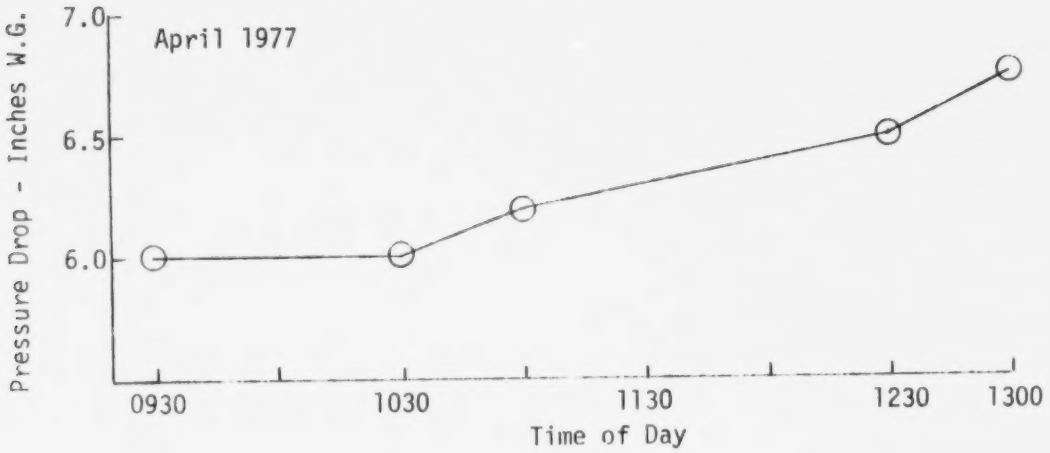

Figure 7

Pressure Drop vs. Time for Experimental Felted Glass Bags With An Air-to-Cloth Ratio of 6.4 - (No Reverse-Air Cleaning)

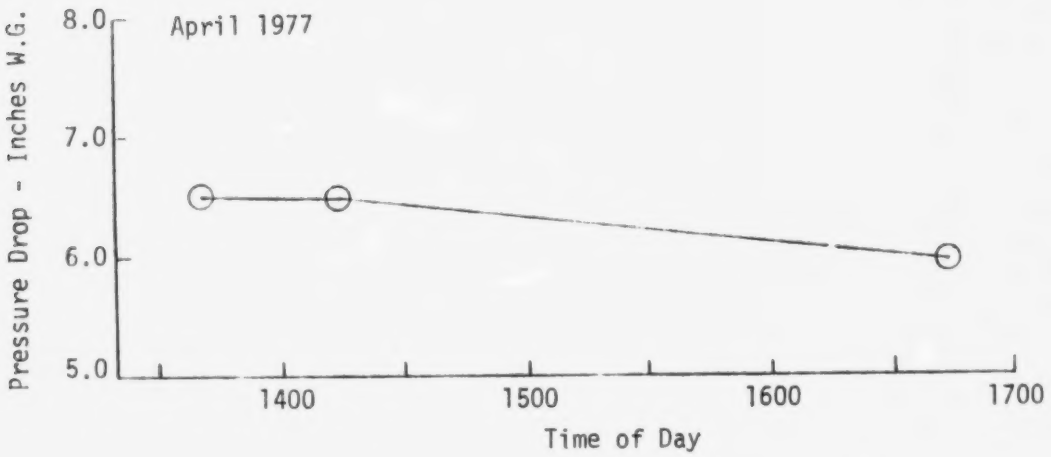

Figure 8

Pressure Drop vs. Time for Experimental Felted Glass Bags During Cleandown (A/C = 6.4)

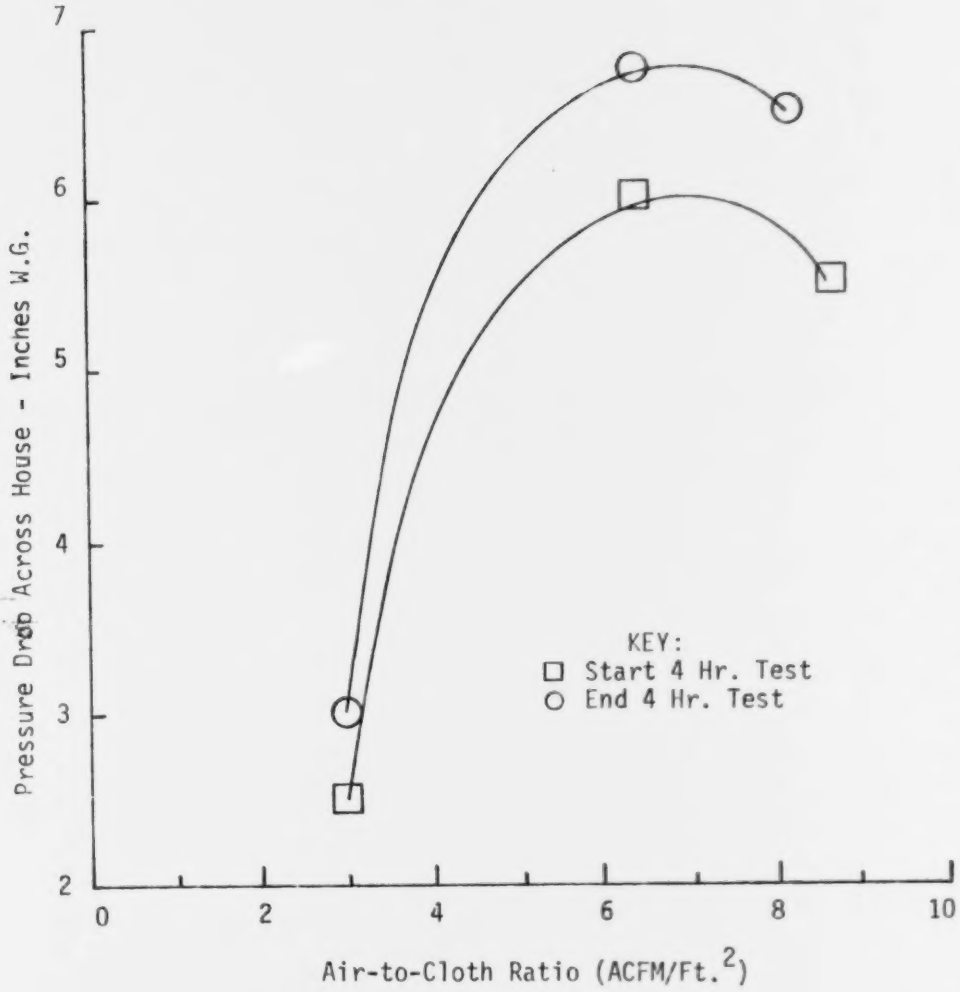

Figure 9

Pressure Drop Across House vs. Air-to-Cloth Ratio
(Experimental Felted Glass Bags)

cloth ratios then begins decreasing again. Pressure drops are not shown for A/C equal to three (3) due to shut down and were not listed for A/C equal to 6.4.

Table 7 lists average outlet concentrations and average particle sizes. Absolute values for each test can be found in Appendices A-4 and A-5 for all filter media. Particle size distribution for the outlet is demonstrated in Figure 10 for air-to-cloth ratios of 3.2, 6.4 and 8.7. In ascending order, the percentages of particulate matter released that is less than three (3) microns are 50%, 41% and 34% respectively. Sub-micron particle percentages in this test were 32%, 25% and 16% for A/C 3.2, 6.4 and 8.7. Inlet particle size data showed approximately 10% of the particulate matter to be sub-micron.

The mass mean average particle diameters at the outlet for the three A/C ratios are 2.81 microns, 4.65 microns and 4.62 microns. Mass efficiencies for these A/C ratios for the old inlet concentration of 0.538 gr/SCFD and the new inlet concentration of 0.329 gr/SCFD are 99.78% and 99.83%, 99.92% and 99.87%, and 99.73% and 99.55% respectively. These are more than acceptable results. Mass efficiencies for individual tests are listed in Appendix A-6.

Woven Glass Bags

Forty woven glass 22½ oz. glass fabric bags with Q78 finish were arranged in the Enviro-Systems & Research baghouse as in Figure 11. The EssTee house was outfitted with 48 bags of the same type.

The first test was to determine pressure drop vs. time for a graphical analysis. Both pilot baghouses were monitored at the same time and the results are in Figures 12 and 13. The curves are roughly similar; however, the Enviro-Systems house has a fairly consistent one inch greater pressure drop than the EssTee baghouse. Due to a visible emission plume at this time, testing was halted on the EssTee house. It appears that the woven glass bags operate in

Table 7

Outlet Concentration and Cumulative %
April 1977

Felted Glass Bags

Air-to-Cloth 3.2/1			Air-to-Cloth 6.4/1			Air-to-Cloth 8.7/1		
Avg. Part. Diam. Microns (1)	Avg. Outlet Conc. gr/SCFD (2)	Cum % (3)	Avg. Part. Diam. Microns	Avg. Outlet Conc. gr/SCFD	Cum %	Avg. Part. Diam. Microns	Avg. Outlet Conc. gr/SCFD	Cum %
9.33	.0001834	100.00%	9.33	.0001770	100.00%	9.33	.0005394	100.00%
6.23	.0000657	68.04	6.23	.0000502	59.02	6.23	.0002472	63.31
4.20	.0000391	56.6	4.20	.0000592	47.43	4.20	.0002162	46.49
2.77	.0000459	49.79	2.77	.0000207	33.76	2.77	.0001229	31.78
1.33	.0000744	41.8	1.33	.0000154	28.99	1.33	.0000849	23.42
0.80	.0000286	28.85	0.80	.0000302	25.54	0.80	.0000697	17.64
0.57	.0000434	23.87	0.57	.0000155	18.57	0.57	.0000338	12.9
0.30	.0000455	16.31	0.30	.0000156	15.0	0.30	.0000485	10.6
0.30	.0000482	8.39	0.30	.0000494	11.40	0.30	.0001073	7.30
TOTAL	.0005742		TOTAL	.0004332		TOTAL	.0014699	

(1) Corrected for Stack Temperature

(2) gr/SCFD - Grains Per Standard Cubic Foot Dry (Standard - 70° F, 29.92" Hg)

(3) Percent of Total Outlet Concentration Less Than Size Indicated

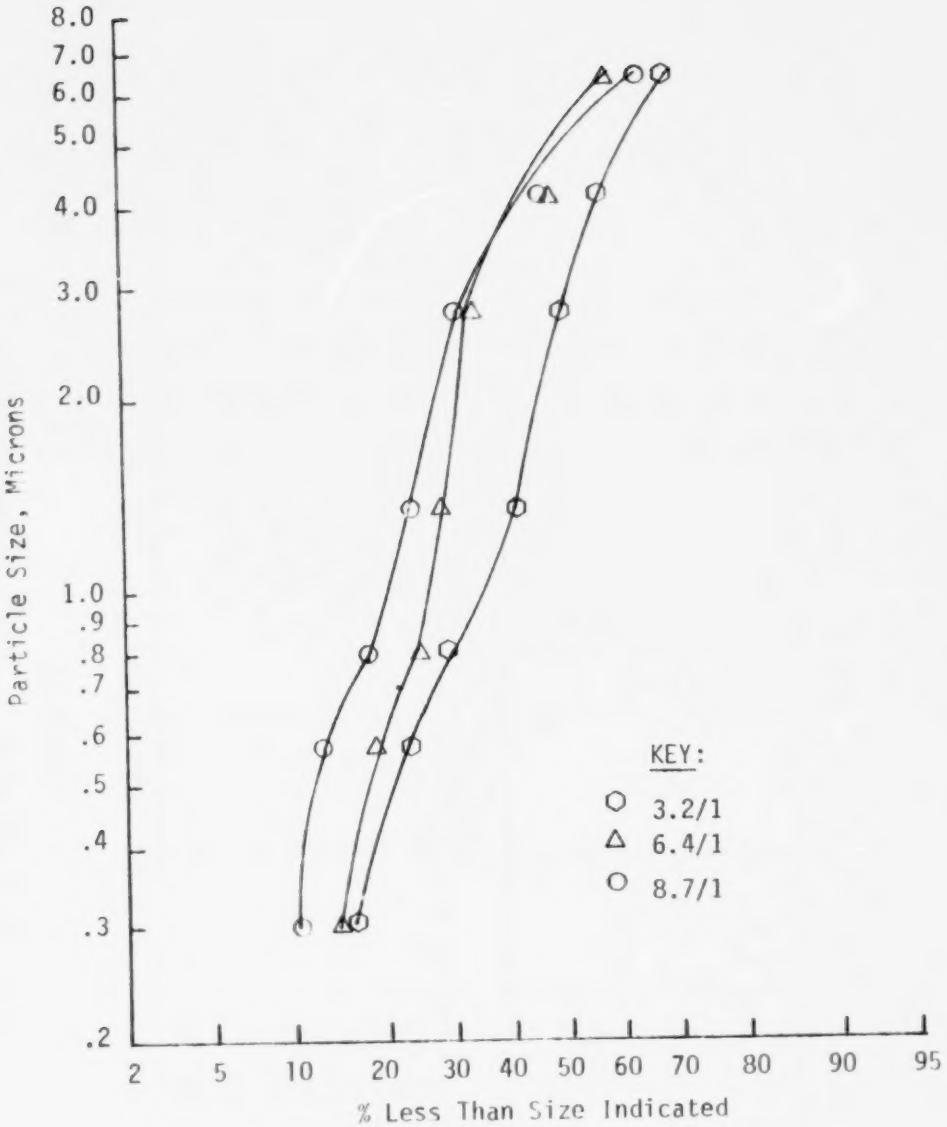

Figure 10

Outlet Particle Size Distribution
(Experimental Felted Glass Bags, April, 1977)

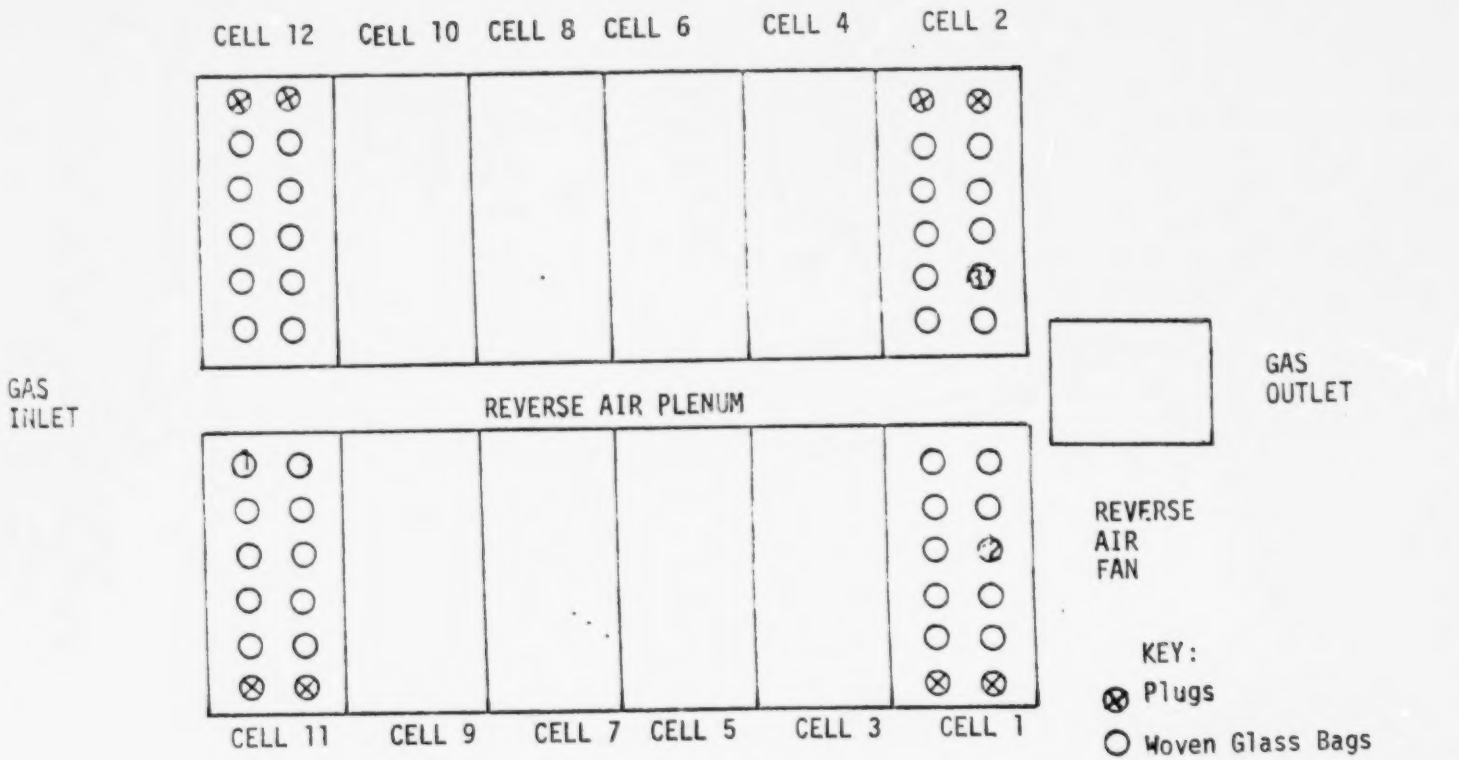

Figure 11

Woven Glass Bag Positioning in Enviro-Systems Baghouse

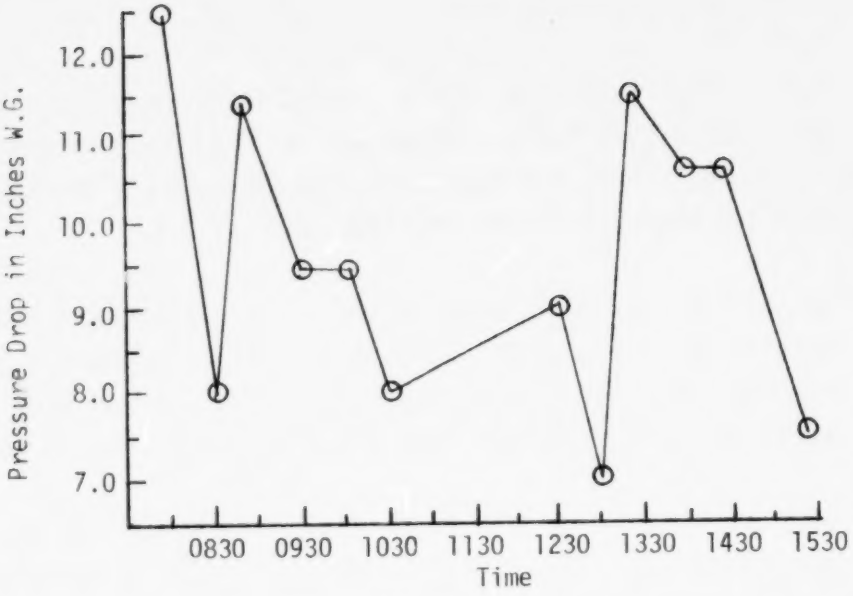

Figure 12

Pressure Drop vs. Time for Woven Glass Bags in the Enviro-Systems Baghouse (No Reverse-Air Cleaning) A/C - 6.7/1

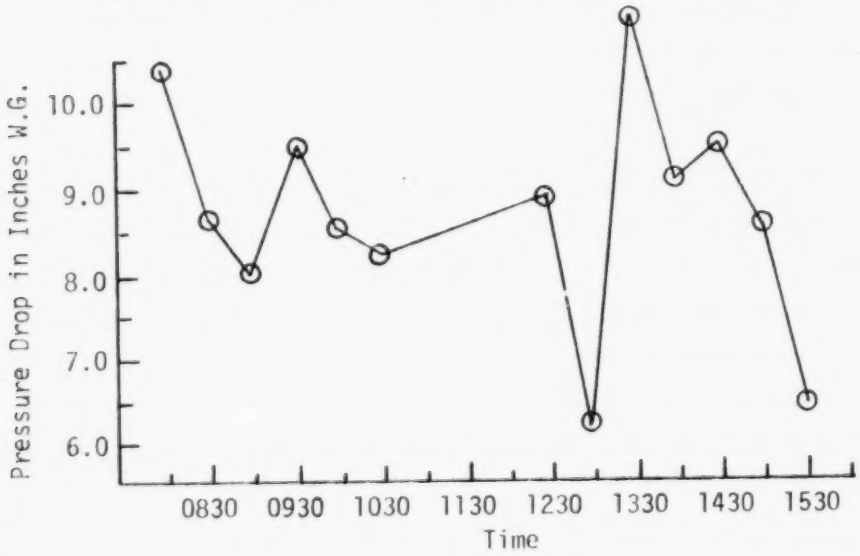

Figure 13

Pressure Drop vs. Time for Woven Glass Bags in the EssTee Baghouse (No Reverse-Air Cleaning) A/C = 6.7/1

a higher pressure drop range than the experimental felted glass bags for the air-to-cloth ratio used.

Two and four hour tests were conducted to determine pressure drop vs. air-to-cloth ratio. For an A/C ratio of 2.75 the pressure drop increased an inch over two hours, but decreased by one-half inch over two hours for an air-to-cloth ratio of 4.1.

In the four-hour test, pressure drop from beginning to end of the test (for an A/C of 4.19) increased an inch. For the A/C of 6.68 the pressure drop did not appear to change, although cleandown did lower the drop by one-half inch W.G. See Figures 14 and 15.

Outlet particle size distributions were determined for two-run averages of the A/C ratios 2.75, 4.2 and 6.7. Half the tests were two hours and half were four hours. Figure 16 shows the particle size distribution for the A/C ratios above. The curves are very close to parallel. The percentages of sub-micron particles released at the baghouse outlet are 19.5% for an air-to-cloth ratio of 2.75, 43% for 4.2, and 75% for 6.7. Earlier inlet data indicated that less than 10% of the particulate entering the baghouse was sub-micron.

The mass mean particle diameters for A/C ratios of 2.75, 4.2 and 6.7 respectively, are 5.28 microns, 1.59 microns and less than 0.17 microns. Average outlet concentrations and relative cumulative percentages are listed in Table 8. The fractional efficiencies with respect to inlet concentrations of 0.329 gr/SCFD (at the new inlet) and 0.538 gr/SCFD (at the old inlet) are 99.75% and 99.86% for an A/C ratio of 2.75, 99.78% and 99.87% for 4.2, and 99.71% and 99.83% for a 6.7 air-to-cloth ratio.

PTFE Laminated Fabric

Forty PTFE laminate bags were placed in the baghouse as diagramed in Figure 17 and pressure drop vs. time was studied. The average

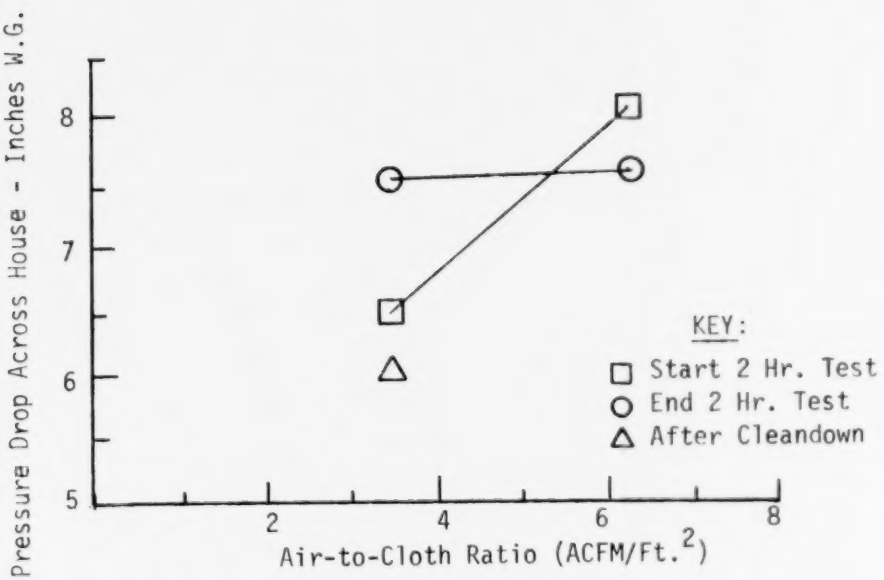

Figure 14

Pressure Drop vs. Air-to-Cloth Ratio for a Two-Hour Test on Woven Glass Bags (No Reverse-Air Cleaning)

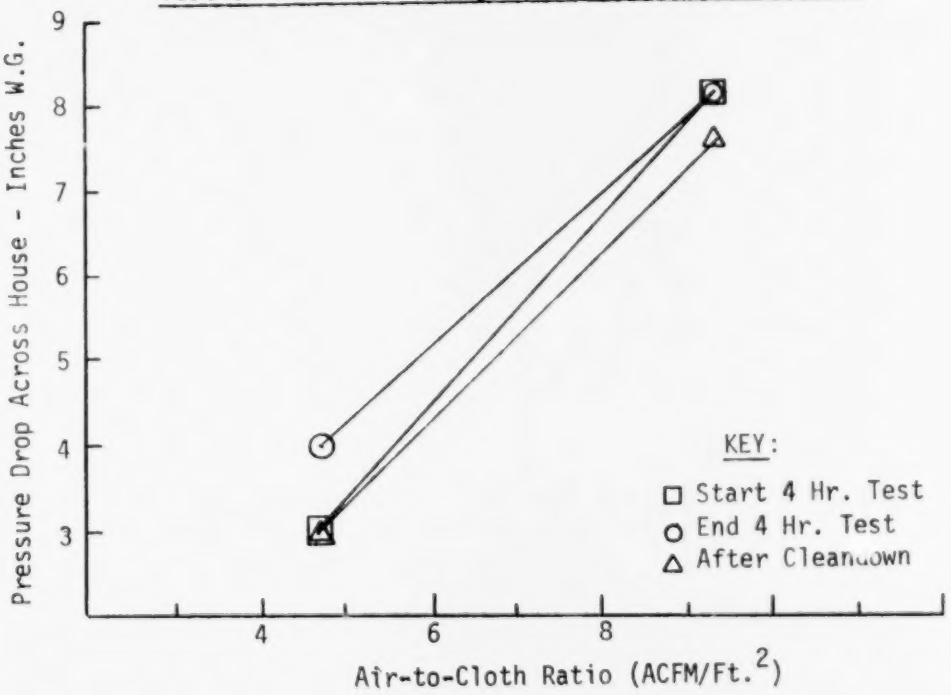

Figure 15

Pressure Drop vs. Air-to-Cloth Ratio for a Four Hour Test on Woven Glass Bags

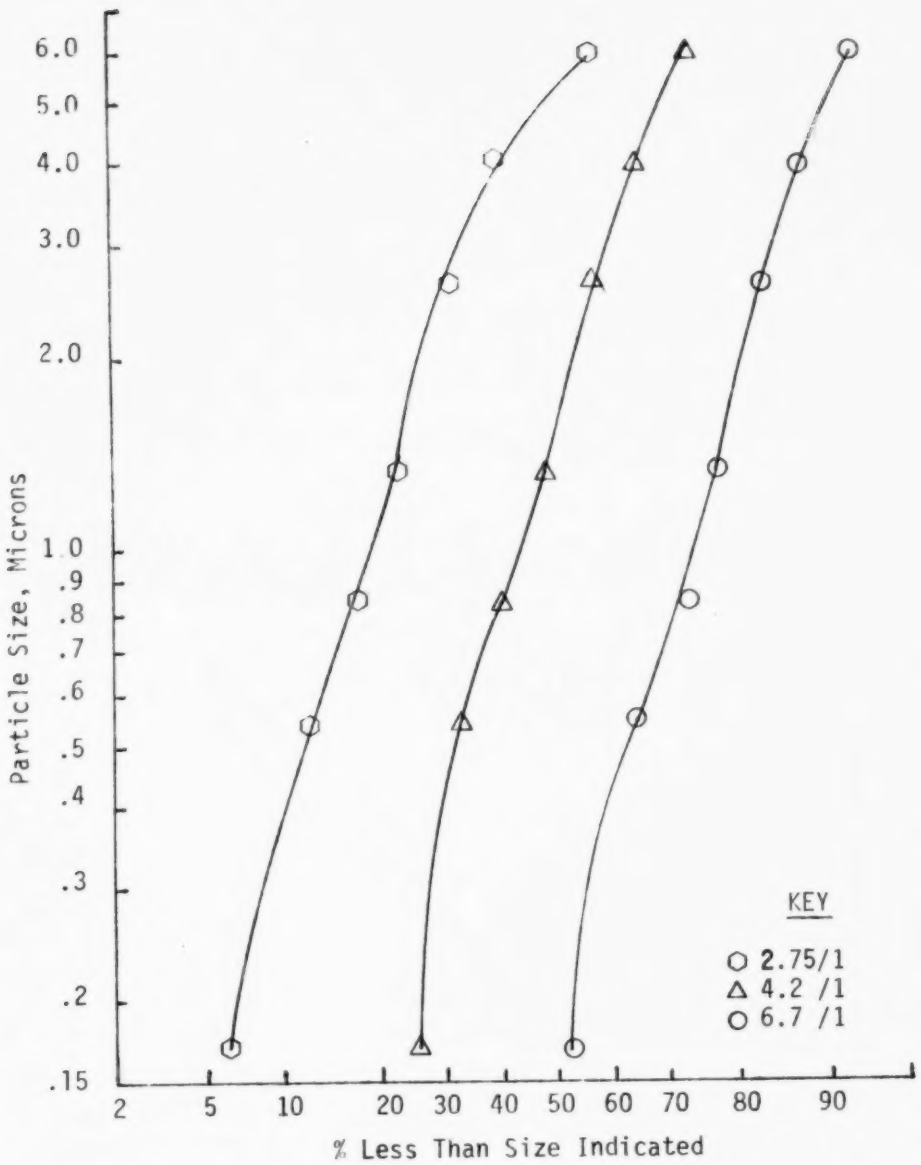

Figure 16

Outlet Particle Size Distribution, Woven Glass

Table 8

Outlet Concentration and Cumulative %
March 1977

Woven Glass Bags

Air-to-Cloth=2.75/1			Air-to-Cloth=4.2/1			Air-to-Cloth=6.7/1		
Avg. Part. Dia. Microns (1)	Avg. Outlet Conc. gr/SCFD (2)	Cum % (3)	Avg. Part. Diam. Microns	Avg. Outlet Conc. gr/SCFD	Cum %	Avg. Part. Diam. Microns	Avg. Outlet Conc. gr/SCFD	Cum %
8.85	.0003446	100.00%	78.85	.0001936	100.00%	78.85	.0001936	100.00%
6.03	.0001473	57.09	6.03	.0000647	73.23	6.03	.0000415	91.63
4.10	.0000631	38.75	4.10	.0000536	64.28	4.10	.0000411	87.33
2.63	.0000625	30.89	2.63	.0000618	56.87	2.63	.0000506	83.07
1.33	.0000417	23.11	1.33	.0000601	48.32	1.33	.0000456	77.83
0.84	.0000431	17.92	0.84	.0000558	40.01	0.84	.0000828	73.01
0.54	.0000515	12.55	0.54	.0000482	32.29	0.54	.0001134	64.44
0.17	.0000493	6.14	0.17	.0001009	25.62	0.17	.0002527	52.69
< 0.17	--		< 0.17	.0000843	11.66	< 0.17	.0002563	26.53
TOTAL	.0008031		TOTAL	.0007230		TOTAL	.0009659	

(1) Corrected for Stack Temperature

(2) gr/SCFD - Grains Per Standard Cubic Foot Dry (Standard - 70° F, 29.92" Hg)

(3) Percent of Total Outlet Concentration Less Than Size Indicated

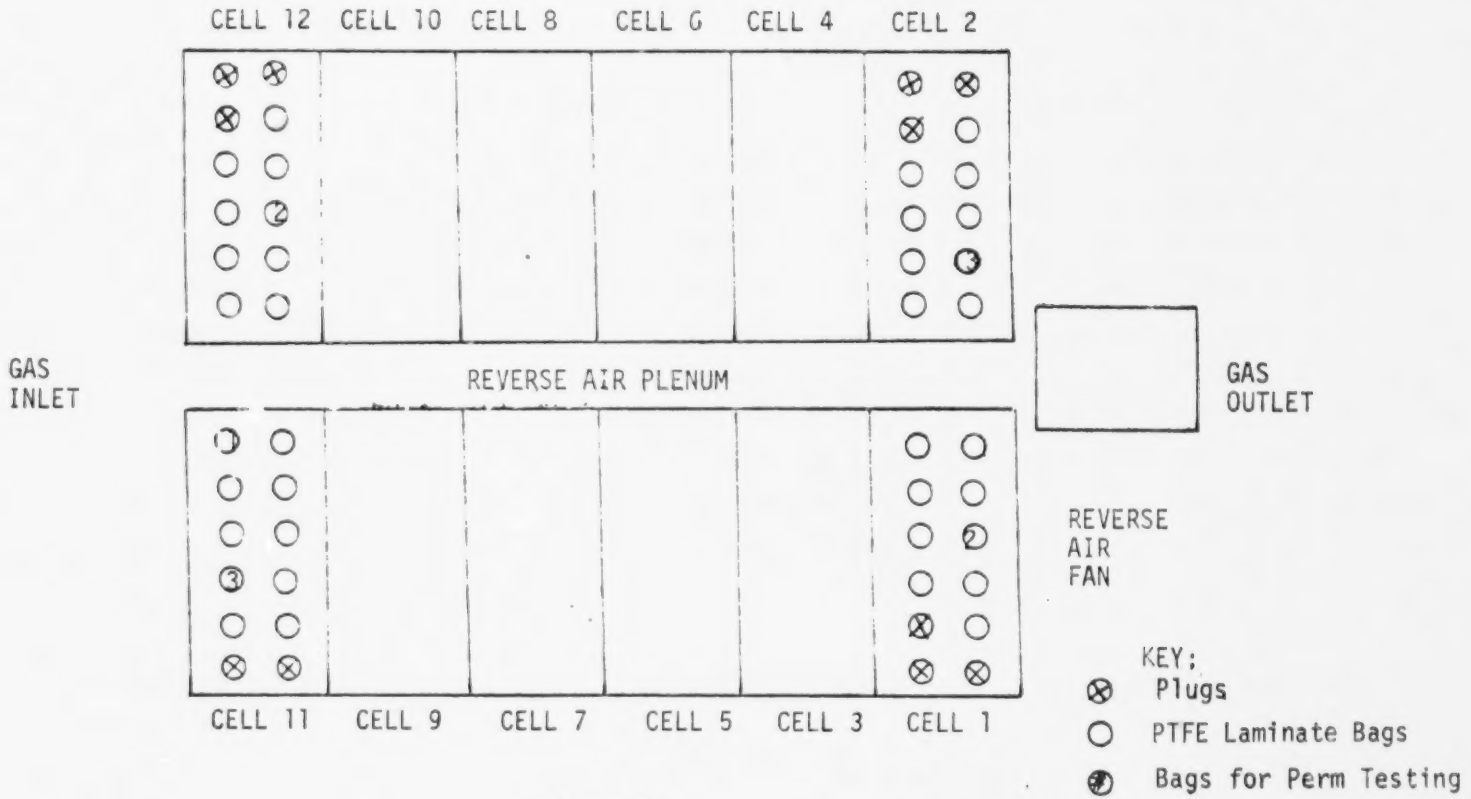

Figure 17

PTFE Laminate Bag Positioning in Enviro-Systems Baghouse

across-house pressure drop was the highest for any of the fabrics used. An hour of cleandown reduced the pressure drop by 1.5" WG. See Figures 18 and 19.

Figures 20 and 21 are graphical representations of pressure drop vs. air-to-cloth ratio for two and four hour runs with no reverse-air cleaning. For an A/C ratio of 4.4 in the two-hour test, the increase in pressure drop was a moderate 0.7" WG but cleandown did not reduce this drop to its original level. For the A/C of 6.3, the pressure drop increased 3.4" WG, but cleandown reduced it to 7" WG. During the four-hour test the pressure drop increased more for the A/C ratio of 4.8 than for the ratio of 7.48. Cleandown improved for the larger air-to-cloth ratio also.

Outlet particle size distributions were determined for two run averages (two-hour run) of the air-to-cloth ratios 4.2 and 6.0. Only one four-hour run was used for A/C equal to 5.4 Particle size data is shown in Figure 22. For air-to-cloth ratios of 4.2, 5.4 and 6, the percentages of sub-micron particles collected by the Andersen impactor are 41%, 18% and 30%. Outlet concentration and cumulative percentages are listed in Table 9. Mass mean particle diameters are 1.86 microns, 3.39 microns and 3.39 microns. Mass efficiencies for 0.329 gr/SCFD (new inlet data) and 0.538 gr/SCFD (old inlet) are 99.84% and 99.90%, 99.80% and 99.87%, and 99.85% and 99.90% for A/C ratios of 4.2, 5.4 and 6, respectively. A comparison of outlet concentrations vs. air-to-cloth ratio for the three filter media tested can be viewed in Figure 23.

A statistical analysis to determine if a significant relationship existed between outlet loading and air-to-cloth ratios can be found in Appendix A-7.

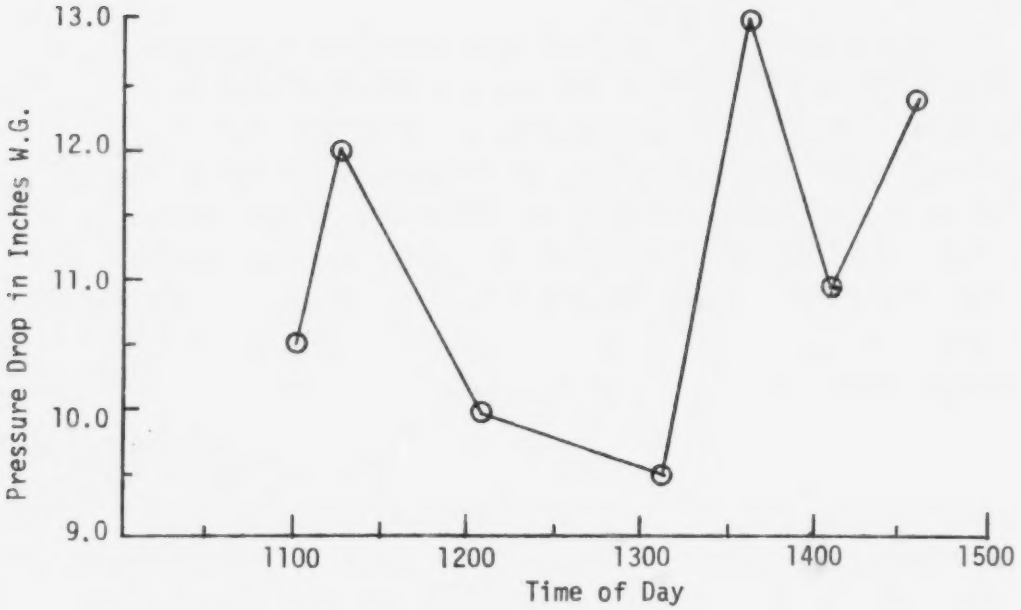

Figure 18

PTFE Laminate 4.8:1 A/C, 3/19/77 (No Reverse-Air Cleaning)

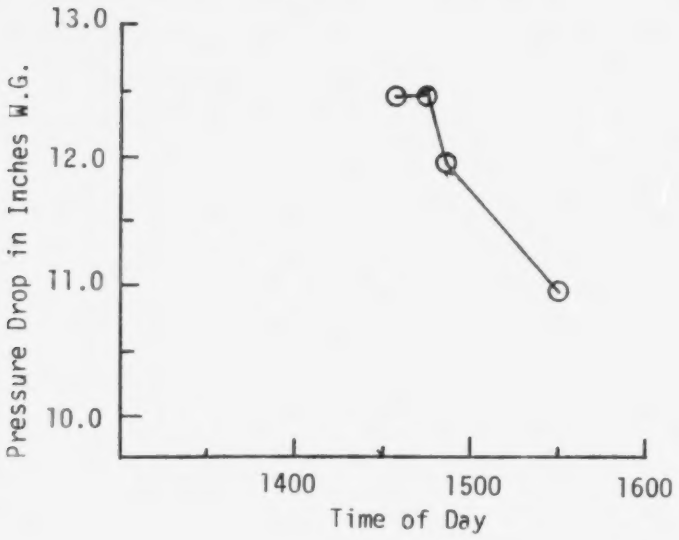

Figure 19

PTFE Laminate Cleandown, 3/19/77

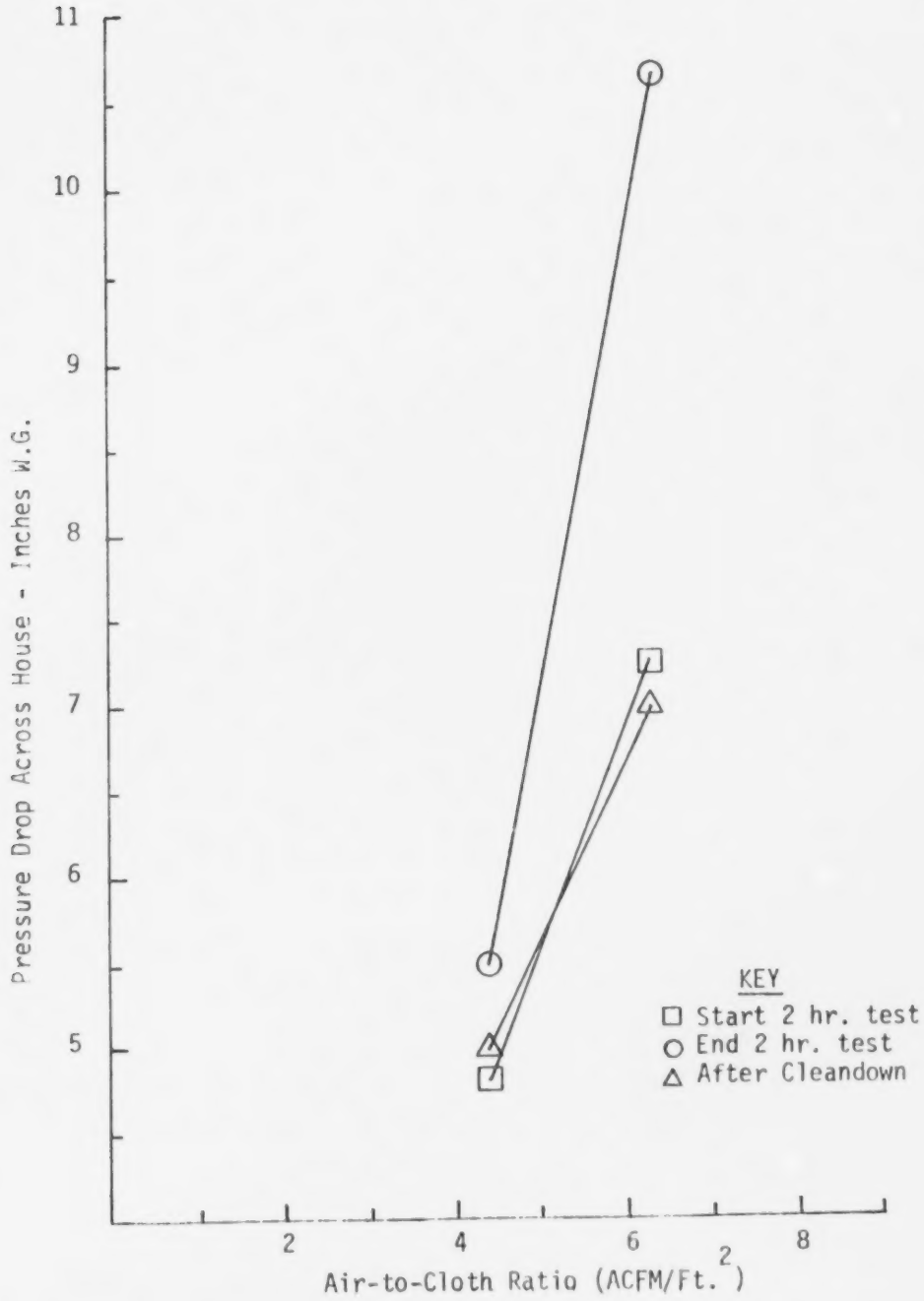

Figure 20

Pressure Drop vs. Air-to-Cloth Ratio for PTFE Laminate Bags Over a Two Hour Test
(Average Values From Two Tests for A/C = 6.3)

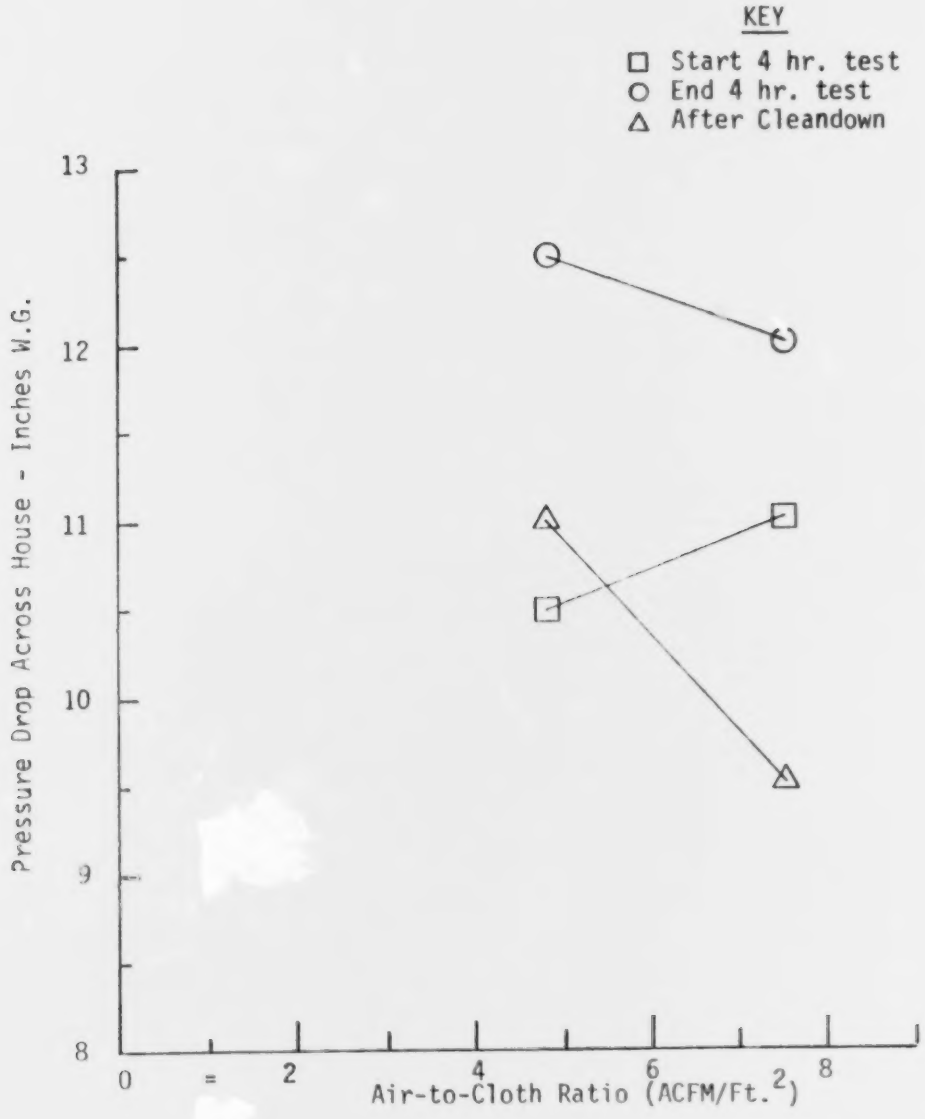

Figure 21

PTFE Laminate Bags (4 Hour Test) -- Pressure Drop vs. Air-to-Cloth Ratio

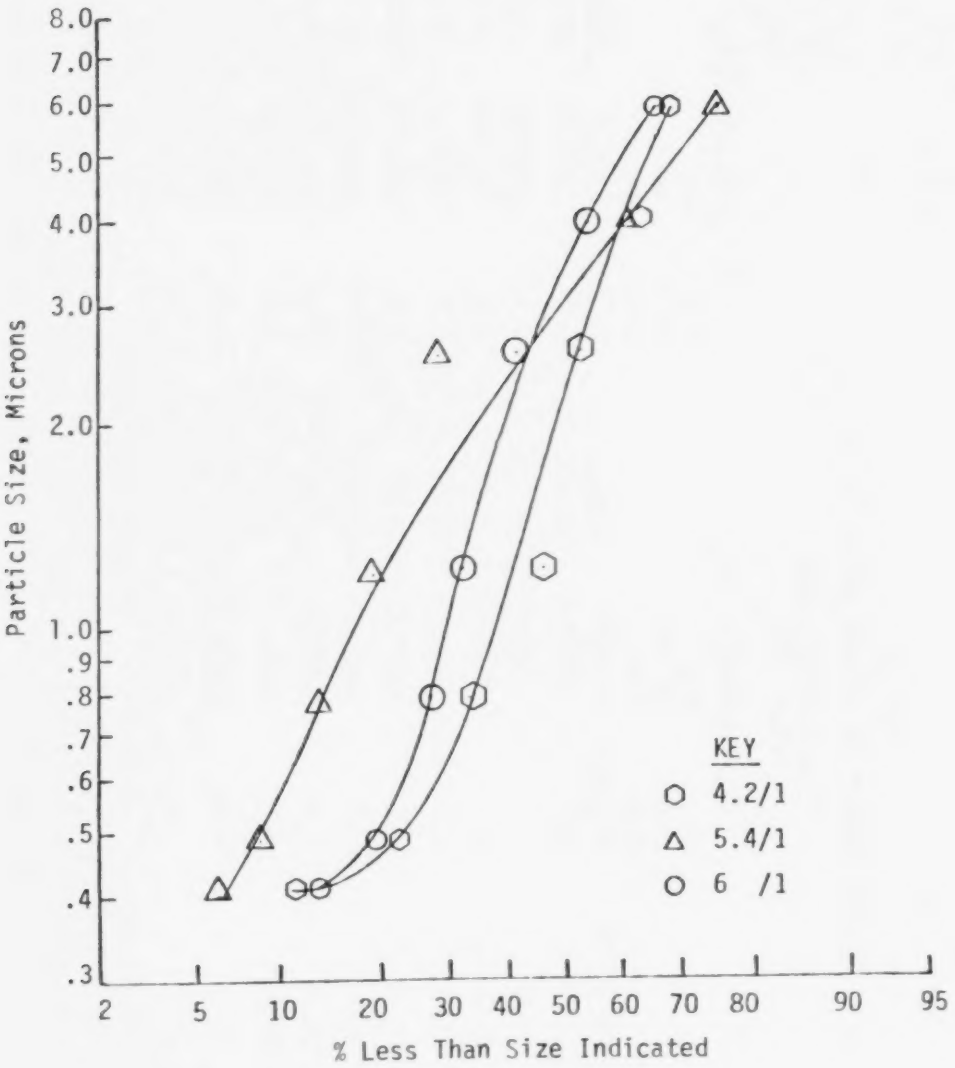

Figure 22

Outlet Particle Size Distribution for PTFE Laminate Fabric

Table 9

Outlet Concentration and Cumulative %

PTFE Laminate Bags

March, 1977

Air-to-Cloth=4.2/1			Air-to-Cloth= 5.4/1			Air-to-Cloth= 6/1		
Avg. (1) Part. Diam. Microns	Avg. (2) Outlet Conc. gr/SCFD	Cum.% (3)	Avg. Part. Diam. Microns	Avg. Outlet Conc. gr/SCFD	Cum.%	Avg. Part. Diam. Microns	Avg. Outlet Conc. gr/SCFD	Cum.%
8.4	.0001760	100.00%	8.4	.0001628	100.00%	8.4	.0001703	100.00%
5.7	.0000235	67.28	5.7	.0000961	75.71	5.7	.0000605	66.75
3.9	.0000512	62.92	3.9	.0002230	61.42	3.9	.0000688	54.94
2.5	.0000372	53.42	2.5	.0000564	28.27	2.5	.0000461	41.51
1.2	.0000666	46.52	1.2	.0000423	19.93	1.2	.0000251	32.51
0.77	.0000637	34.16	0.77	.0000333	13.64	0.77	.0000346	27.61
0.48	.0000581	22.34	0.48	.0000179	8.74	0.48	.0000374	20.86
0.41	.0000221	11.56	0.41	.0000179	6.08	0.41	.0000213	13.56
< 0.41	.0000402	7.46	< 0.41	.0000230	3.42	< 0.41	.0000482	9.40
TOTAL	.0005388			.0006727			.0005123	

(1) Corrected for Stack Temperature

(2) The outlet concentration for the Air-to-Cloth ratio of 5.4 was not an average of two values; gr/SCFD - Grains Per Standard Cubic Foot Dry (Standard - 70° F, 29.92" Hg)

(3) Percent of Total Outlet Concentration Less Than Size Indicated

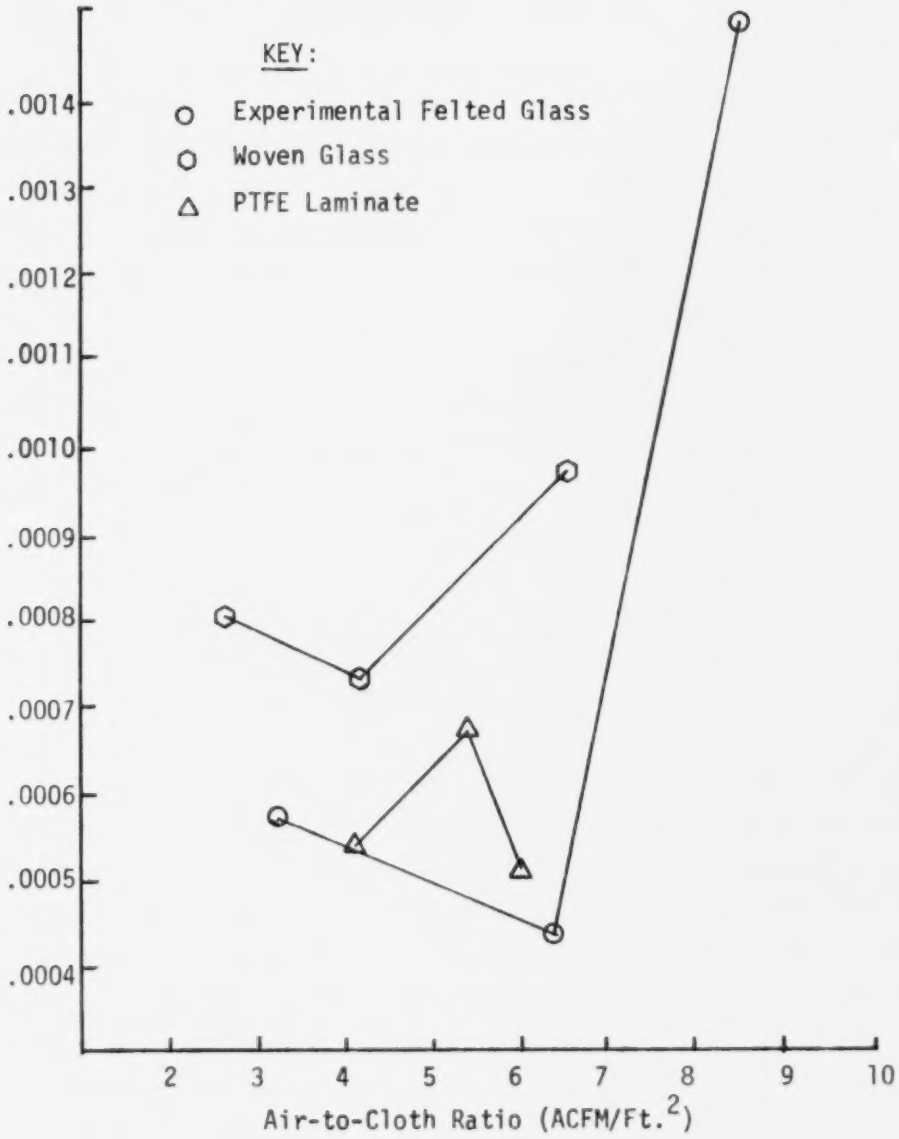

Figure 23

Comparison of Three Fabrics for Outlet Concentration vs. Air-to-Cloth Ratio

ECONOMIC CONSIDERATIONS

The economics of applying a fabric filter to the refuse-fired boilers at NTTC were evaluated and their acceptability compared with an electrostatic precipitator and a wet scrubber. The NTTC boilers (Phase I Report: Pilot Baghouse Test Program for Control of Particulate Emission from the Refuse Fueled Boiler Plant; Sanders & Thomas, Inc., January, 1977):

> ...were fitted with a mechanical cyclone dust collector followed by a low-energy (15 psi water; 4" H_2O gas side pressure drop) wet scrubber.
>
> The scrubbers were intended to remove the flue gas particulate matter by agglomeration of the dust particles in three stages of atomized water spray and moisture elimination.
>
> Initial operation of the plant demonstrated that the wet scrubbers were successful in removing only the larger particle sizes and that the plume resulting from the sub-micron particulate was unacceptable.

The baghouses were insulated and removal of collected particulate was limited to placing dumpsters under each hopper. Installed costs were calculated for a fabric filter dust collector sized to handle 140,000 ACFM at 460° F. The costs were developed for four (4) filter media: (1) 22½ oz. woven glass fabric with Q78 finish, (2) PTFE laminate, (3) experimental felted glass fabric, and (4) Teflon felt. Air-to-cloth ratios considered in each case were 2.9, 5.8, 8.9 and 11.3. Fabric filter (baghouse) sizes are listed in Table 10. Annual operating and annualized costs were also determined for each case. Example calculations for all costs, based on Edminsten and Bunyard methods, can be found in Appendix A-8.

Table 10

Fabric Filter Unit Size vs. Air-to-Cloth Ratio

Air-to-Cloth Ratio	Number of Cells	Number of Bags	Net Filter Area Sq. Feet
2.9	120	4320	47,960
5.8	60	2160	23,980
8.9	40	1440	15,700
11.3	32	1152	12,400

Installed Costs

The installed costs (flange-to-flange hardware plus installation) for a baghouse employing the woven glass filters based on air-to-cloth ratios of 2.9, 5.8, 8.9 and 11.3 were found to be $817,260, $421,750, $316,734 and $271,837, based on an installation cost that is 70% of the flange-to-flange price. On the basis of $/ACFM this becomes $5.84, $3.01, $2.26 and $1.94 respectively. These cost estimates were based on a bag price of $17.25 each (vendor quote - September 1976).

The installed cost estimates for bags of the experimental felted glass fabric were $928,522, $477,381, $353,821 and $301,505, or a $/ACFM cost of $6.63, $3.41, $2.53 and $2.15. These costs are based on an April, 1977 vendor quote of $32.40 per bag.

The PTFE laminate installed cost estimates were $1,068,792, $547,516, $400,578 and $338,912 with $/ACFM costs being $7.63, $3.91, $2.86 and $2.42. These figures are based on a vendor quote of $51.50 per bag (September, 1976).

Although Teflon felt bags were not actually tested, a cost analysis was made based on a price of $68.00 per bag (vendor quote, September 1976). The installed costs were $1,189,968, $608,104, $440,970 and $371,226. The costs in $/ACFM were $8.50, $4.34, $3.15 and $2.65, respectively.

Installed costs vs. air-to-cloth ratio can be viewed graphically in Figure 24. Note from the graph that Teflon felt is the most expensive and woven glass the least expensive through the range of air-to-cloth ratios examined. The difference in installed cost between these two media decrease considerably, however, as the air-to-cloth ratio increases. This is due to the decreasing percentage of total cost atrributed to the bags as the size of the house

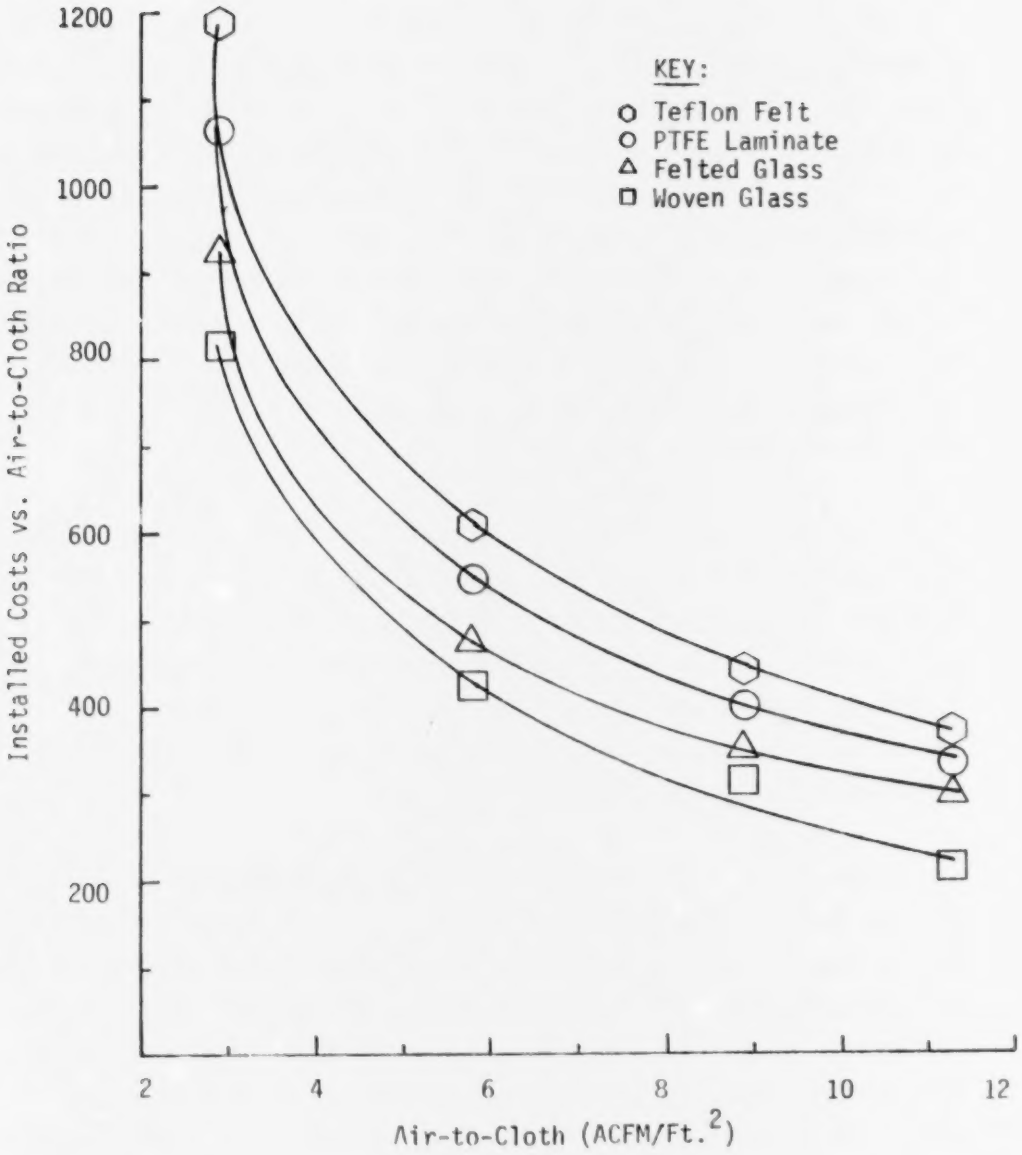

Figure 24

Comparison of Four Filter Media for Installed Costs vs. Air-to-Cloth Ratio

decreases. Table 11 lists the percentage of installed cost for bags at each air-to-cloth ratio examined.

The installed costs for an electrostatic precipitator capable of handling 140,000 ACFM were $855,180 or $6.10 ACFM for 98.5% efficiency and a total pressure drop of 2" WG. This cost was developed by adding the flange-to-flange cost of $390,180 given by American Air Filter Company, Inc. of Louisville, Tennessee, plus $465,000 for erection and fans (actual cost cited by Sanders & Thomas, Inc.). The The second precipitator was installed at a total cost of $1.1 million in July 1977, but it included considerably more extraneous equipment. The fractional efficiency is based on the assumption that inlet loading would be at least 1.5 gr/SCFD (adjusted to 12% CO_2) to yield an outlet loading less than 0.0225 gr/SCFD.

Installed costs for a wet scrubber capable of handling 140,000 ACFM with 99% efficiency and a pressure drop of 30" WG were derived by doubling the figure of $316,000 for 70,000 ACFM given in the article "Performance and Cost Comparison Between Fabric Filters and Alternate Particulate Control Techniques" (McKenna, et al) and adding 12% for escalation. The installed cost arrived at by this method was $707,840 or $5.06/ACFM.

Comparing the three methods of particulate control as in Figure 25, the fabric filter technique for air-to-cloth ratios of 5.8/1 and greater on all bags considered has the lowest installed cost and the electrostatic precipitator the highest. However, should an air-to-cloth ratio of 2.9/1 be required, fabric filters would be the most expensive (except for the woven glass bags which would make the electrostatic precipitator the most expensive) and the wet scrubber the least expensive method.

Table 11

Bag Cost as Percent of Installed Cost

	Installed Cost	Bag Cost	% of Installed Cost for Bags
Woven Glass ($17.25/Bag)			
2.9	817,260	74,520	9.1
5.8	421,750	37,260	8.8
8.9	316,734	24,840	7.8
11.3	271,837	19,872	7.3
Felted Glass ($32.40/Bag)			
2.9	928,522	139,968	15.1
5.8	477,381	69,984	14.7
8.9	353,821	46,656	13.2
11.3	301,505	37,325	12.4
PTFE Laminate ($51.50/Bag)			
2.9	1,068,792	222,480	20.8
5.8	547,516	111,240	20.3
8.9	400,578	74,160	18.5
11.3	338,912	59,328	17.5
Teflon Felt (68/Bag)			
2.9	1,189,968	293,760	24.7
5.8	608,104	146,880	24.1
8.9	440,970	97,920	22.2
11.3	371,226	78,336	21.1

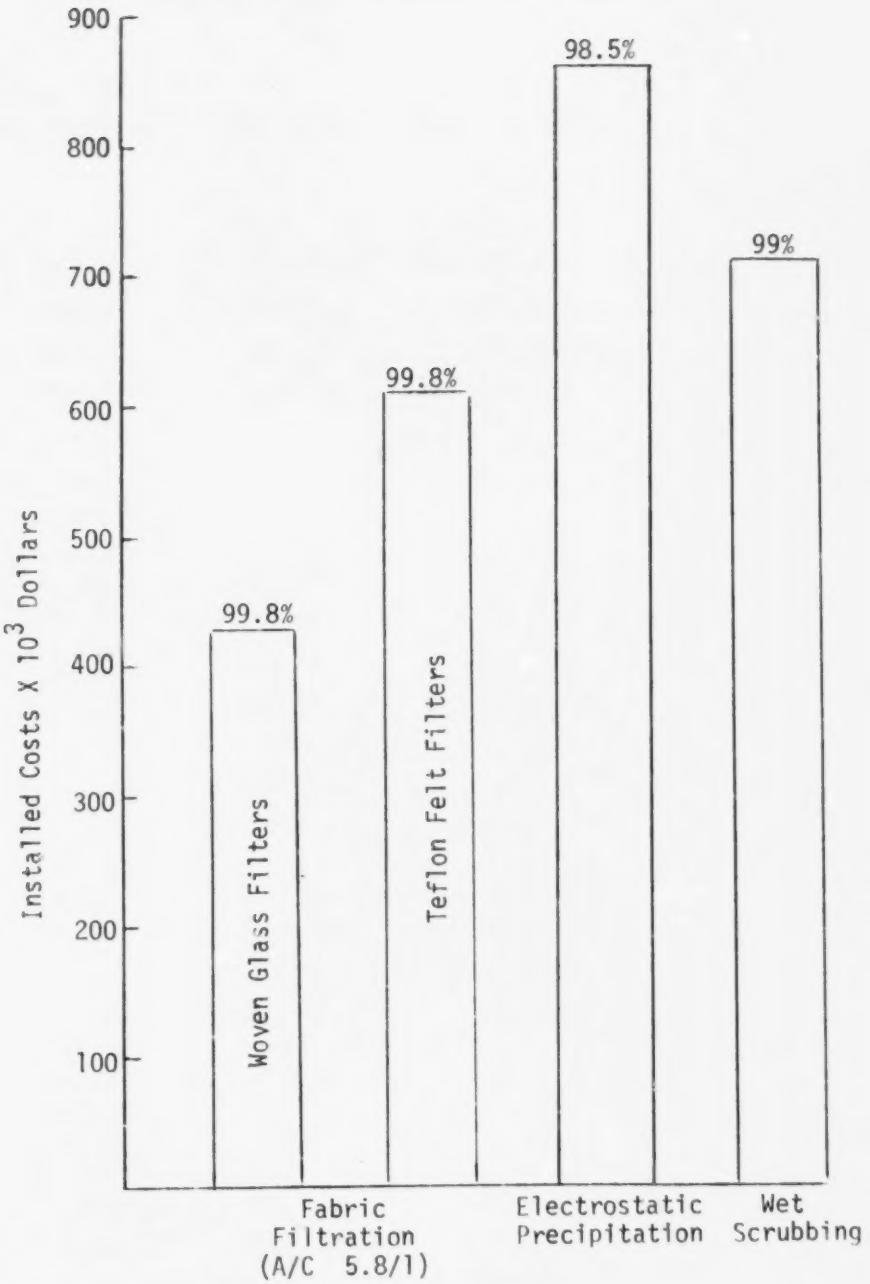

Figure 25

Installed Cost Comparisons for Different Air Pollution Control Techniques (At Slightly Different Efficiencies)

Operating Costs

Annual operating costs were determined for all four filter types for one through five year bag life assumptions. These costs were based on 6" WG for an air-to-cloth ratio of 2.9, 7" WG for 5.8, 10.5" WG for 8.9 and 12.5" WG for 11.3 (1.5" WG of each value was added for pressure drop across the inlet duct, etc.) and electricity rates were actuals ($0.025/KWH) obtained from NTTC. Sample calculations can be found in Appendix A-8. These costs can be seen graphically in Figures 26 through 29 and are listed in Table 12. In all cases, cost decreases as the air-to-cloth ratio increases from 2.9 to 5.8. By increasing the air-to-cloth ratio to 8.9 in the first and all subsequent years, however, the woven glass filters began to increase in annual operating cost. Cost also begins to increase for the experimental felted glass fabric at an air-to-cloth ratio equal to 8.9 for a two-year bag life. Cost increases for PTFE laminate at an air-to-cloth ratio of 8.9 for a three-year bag life, but it also increased at an air-to-cloth ratio of 11.3 for a two-year bag life. The Teflon felt cost increased at 8.9 for a four-year bag life and at 11.3 for a three-year. These increases may be compared more easily by examination of Figures 30 through 34 in which operating cost vs. air-to-cloth ratios are plotted for all bags each year.

Operating costs normally decrease as the air-to-cloth ratio increases due to the decreasing number of bags employed. Therefore, the increasing costs previously noted should be explained. In the formula for calculating annual operating costs for a specific bag life, only two variables exist:

1. The number of bags (which decrease with increasing A/C).
2. The pressure drop (which increases with increasing A/C).

It appears that at some point in the increase of the air-to-cloth ratio for a particular bag life, the effect of the increase in pressure drop outweighs the effect of the decrease in number of bags required -- thus creating this increasing cost.

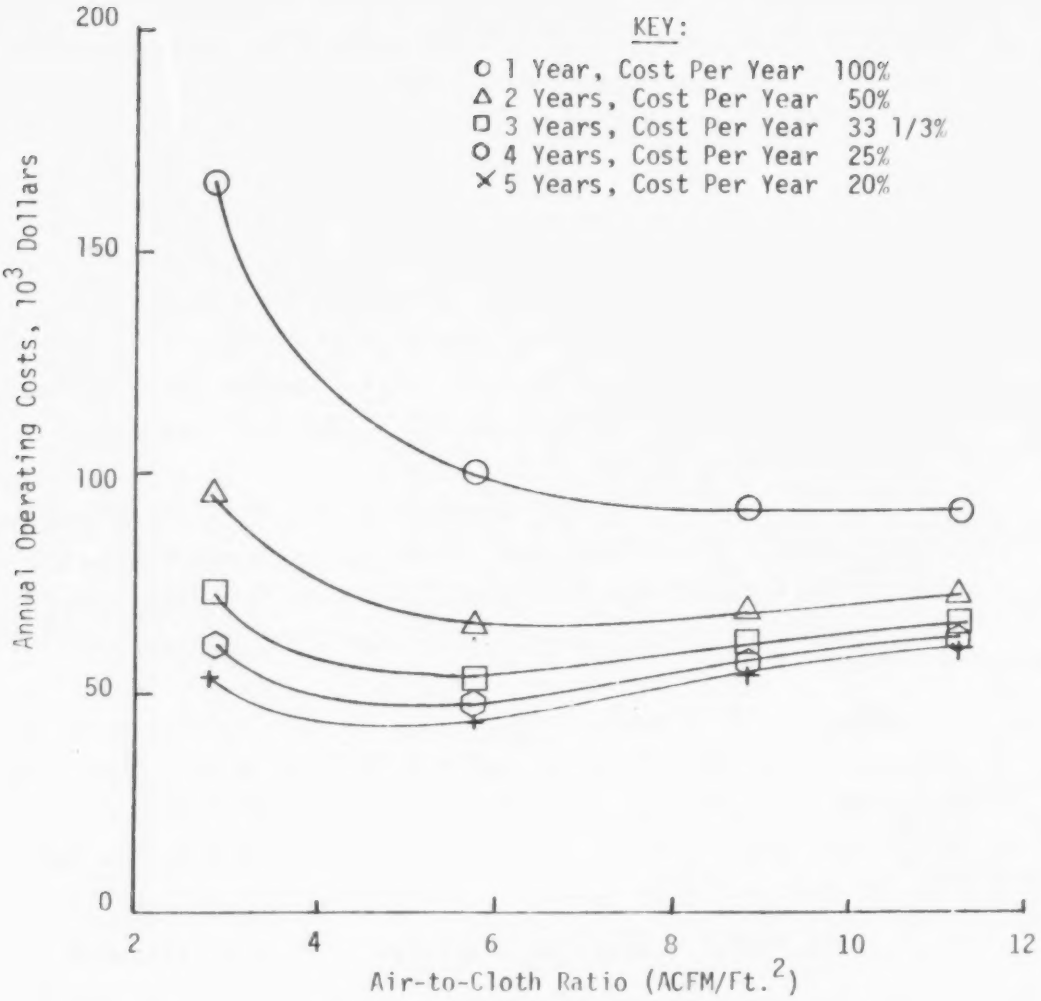

Figure 26

Annual Operating Cost vs. Air-to-Cloth Ratio for Different Bag Life Assumptions for Experimental Felted Glass Fabric Bags

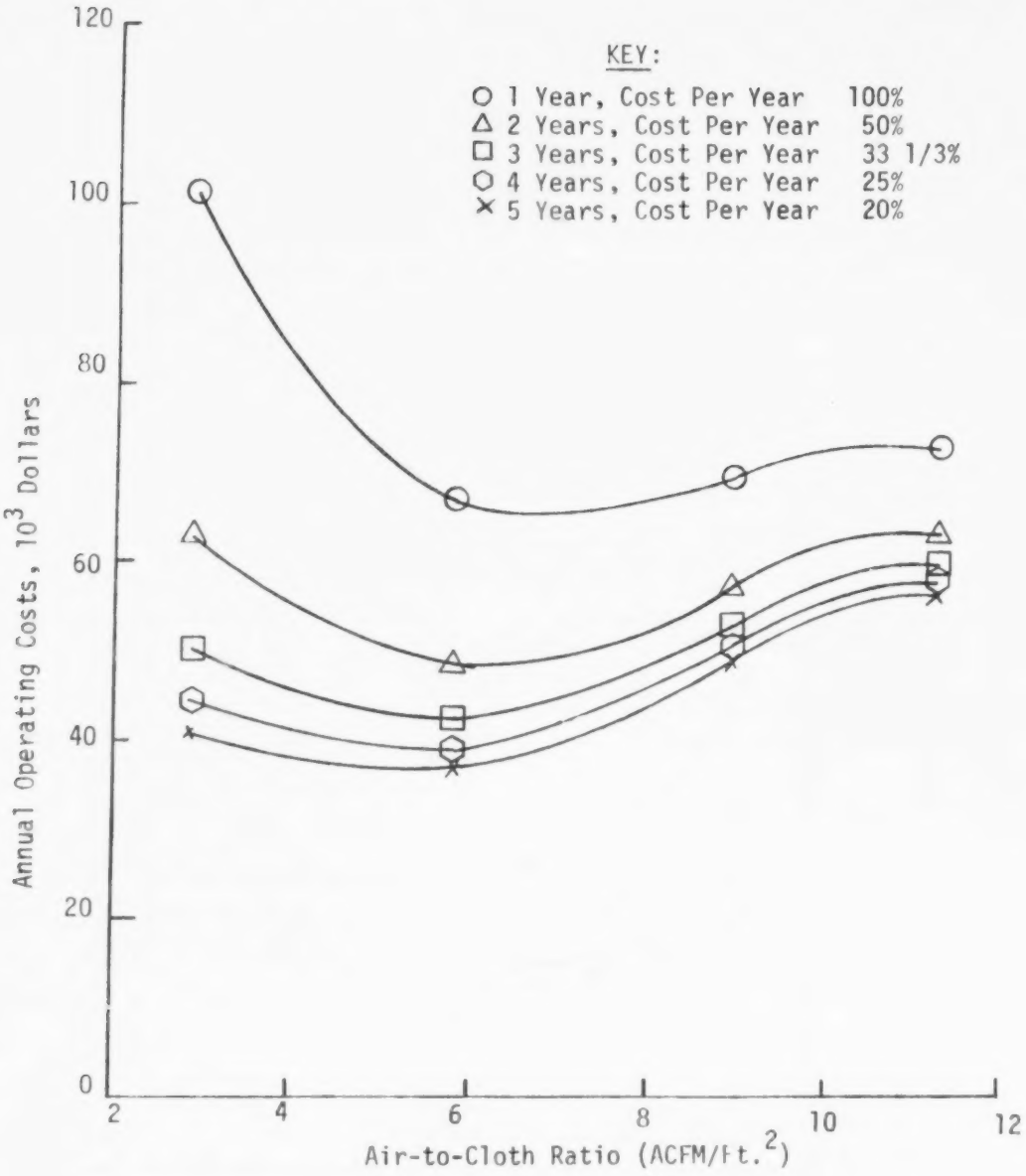

Figure 27

Annual Operating Costs vs. Air-to-Cloth Ratio for Different Bag Life Assumptions for Woven Glass Bags

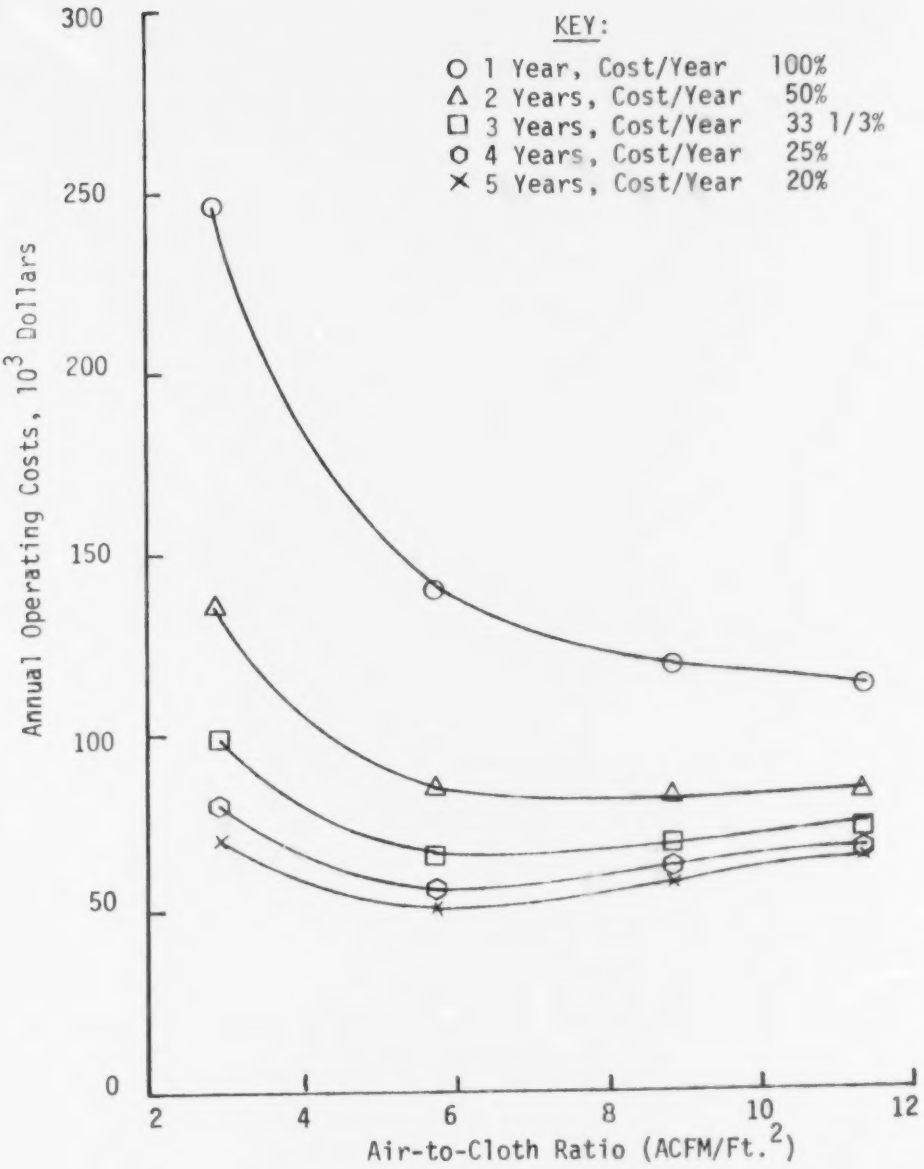

Figure 28

Annual Operating Costs vs. Air-to-Cloth Ratio
for Different Bag Life Assumptions for PTFE Laminate Bags

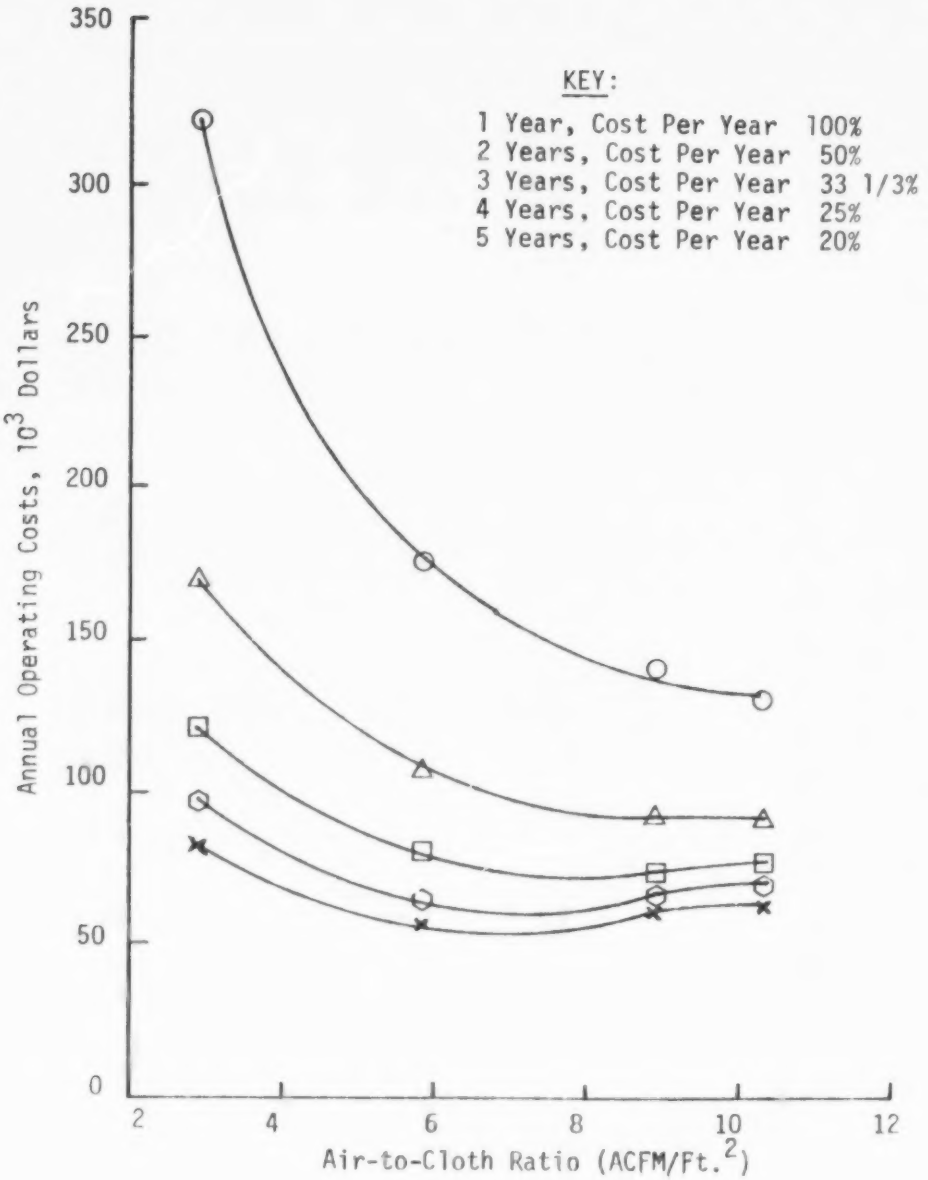

Figure 29

Annual Operating Costs vs. Air-to-Cloth Ratio for Different Bag Life Assumptions for Teflon Felt Bags

Table 12

Annual Operating Costs for Fabric Filters

Filter	A/C	Bag Life 1 Year	2 Years	3 years	4 Years	5 Years
Woven Glass	2.9	$100,142	$ 62,874	$ 50,442	$ 44,254	$ 40,530
Experimental Felted Glass	2.9	165,592	95,606	72,226	60,606	53,620
PTFE Laminate	2.9	248,094	136,864	99,708	81,242	70,112
Teflon Felt	2.9	319,382	172,494	123,438	99,064	84,378
Woven Glass	5.8	67,144	48,524	42,294	39,200	37,338
Experimental Felted Glass	5.8	99,876	64,876	53,200	47,390	43,890
PTFE Laminate	5.8	141,134	85,512	66,934	57,694	52,136
Teflon Felt	5.8	176,764	103,334	78,806	66,612	59,262
Woven Glass	8.9	69,678	57,260	53,116	51,058	49,812
Experimental Felted Glass	8.9	91,504	68,166	60,382	56,504	54,180
PTFE Laminate	8.9	119,000	81,928	69,538	63,378	59,668
Teflon Felt	8.9	142,758	93,800	77,448	69,328	64,428
Woven Glass	11.3	73,248	63,322	60,004	58,352	57,358
Experimental Felted Glass	11.3	90,706	72,044	65,814	62,720	60,844
PTFE Laminate	11.3	112,714	83,048	73,136	68,208	65,254
Teflon Felt	11.3	131,712	92,554	79,464	72,968	69,048

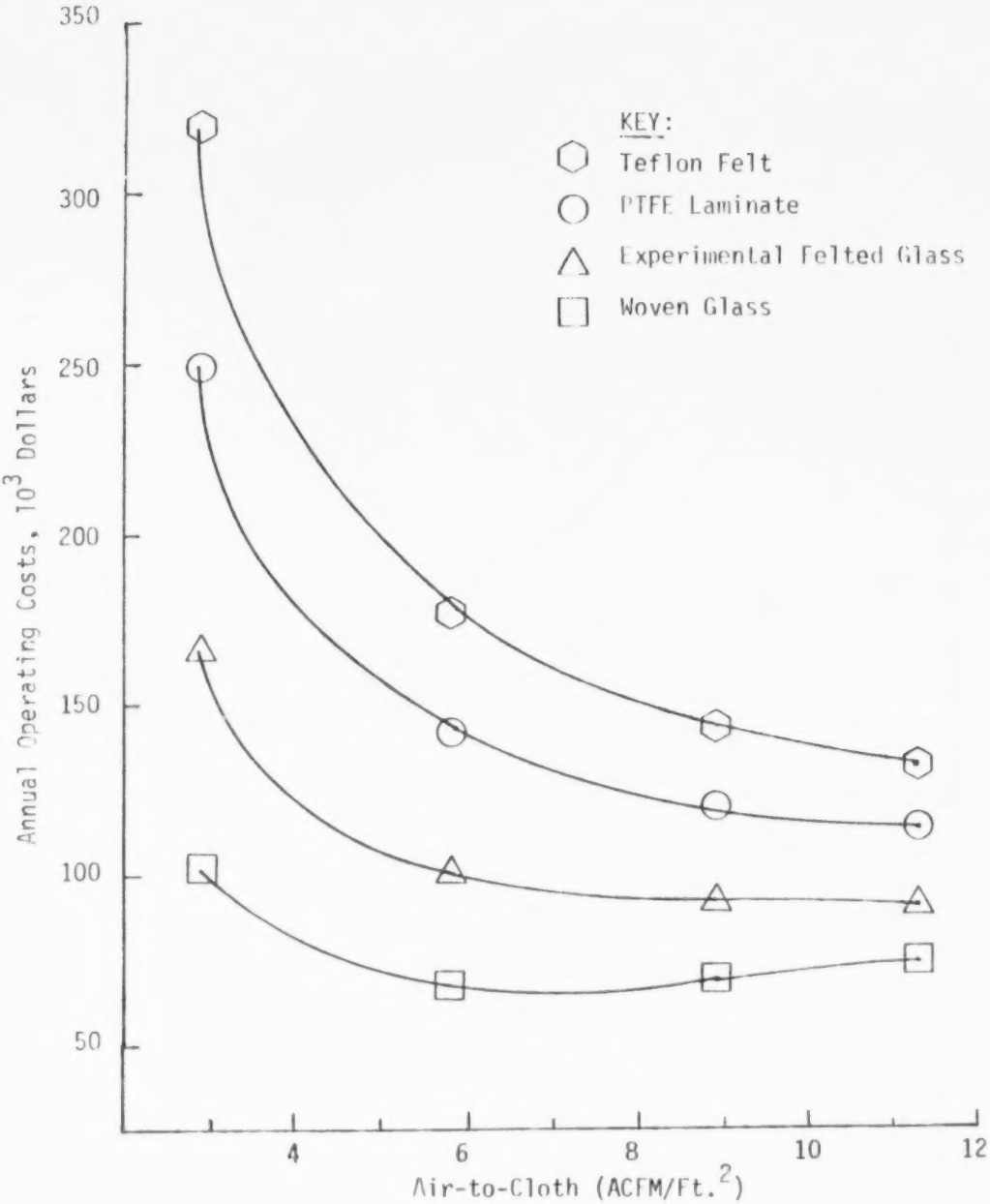

Figure 30

Comparison of Annual Operating Costs vs. Air-to-Cloth Ratio for All Media Assuming a One Year Bag Life

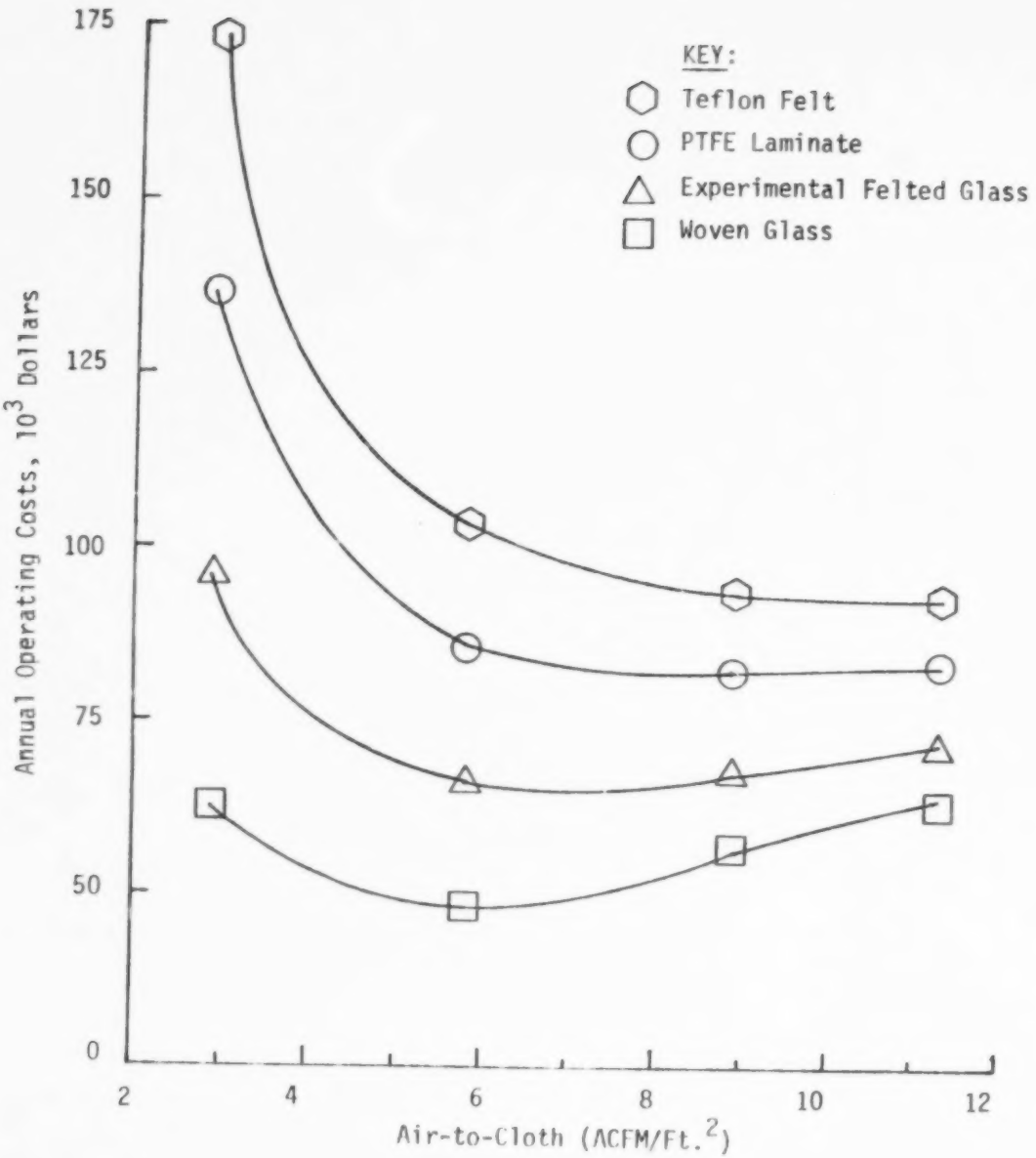

Figure 31

Comparison of Annual Operating Costs vs. Air-to-Cloth Ratio for All Media Assuming a Two Year Bag Life

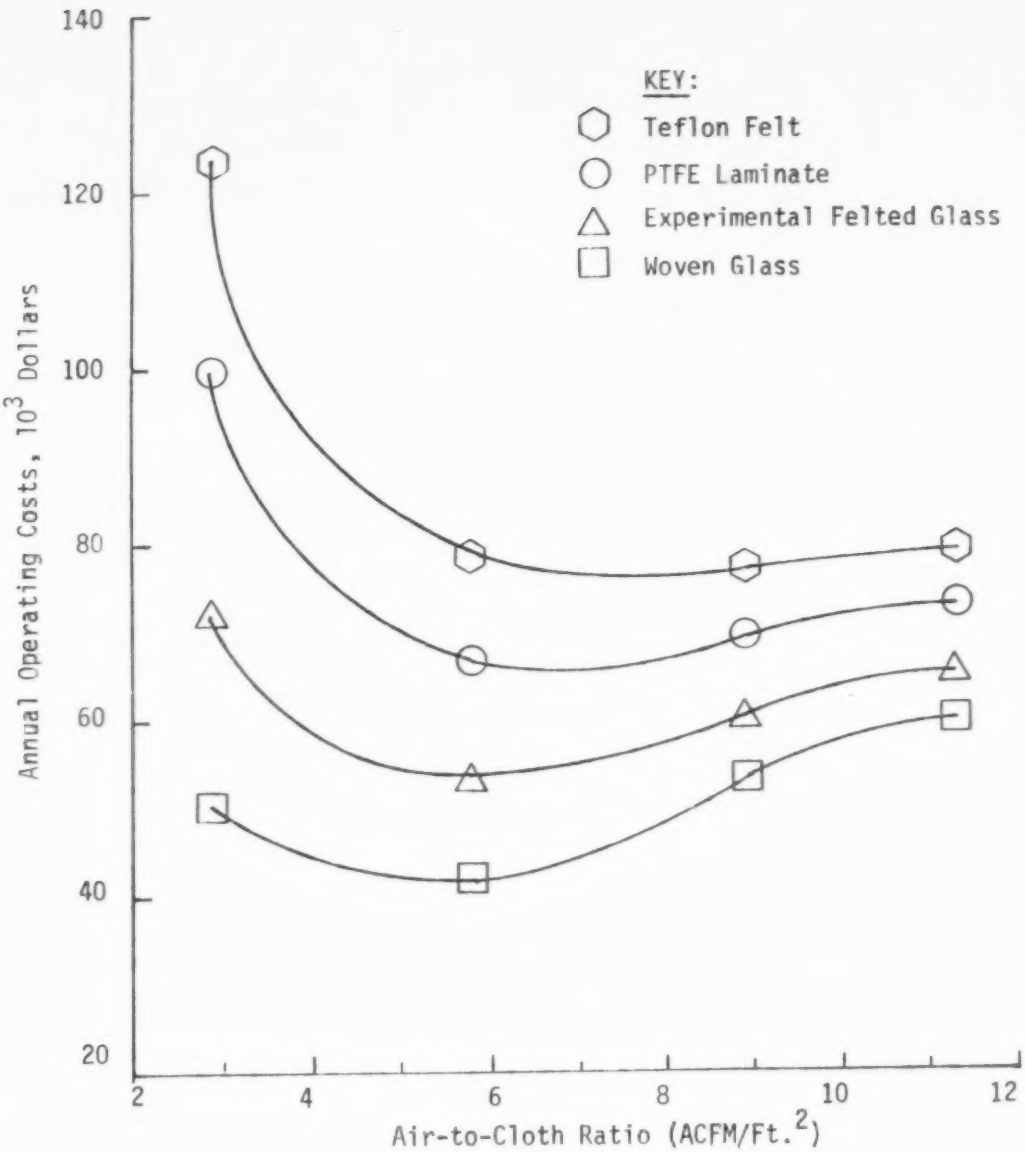

Figure 32

Comparison of Annual Operating Costs vs. Air-to-Cloth Ratio for All Media Assuming a Three Year Bag Life

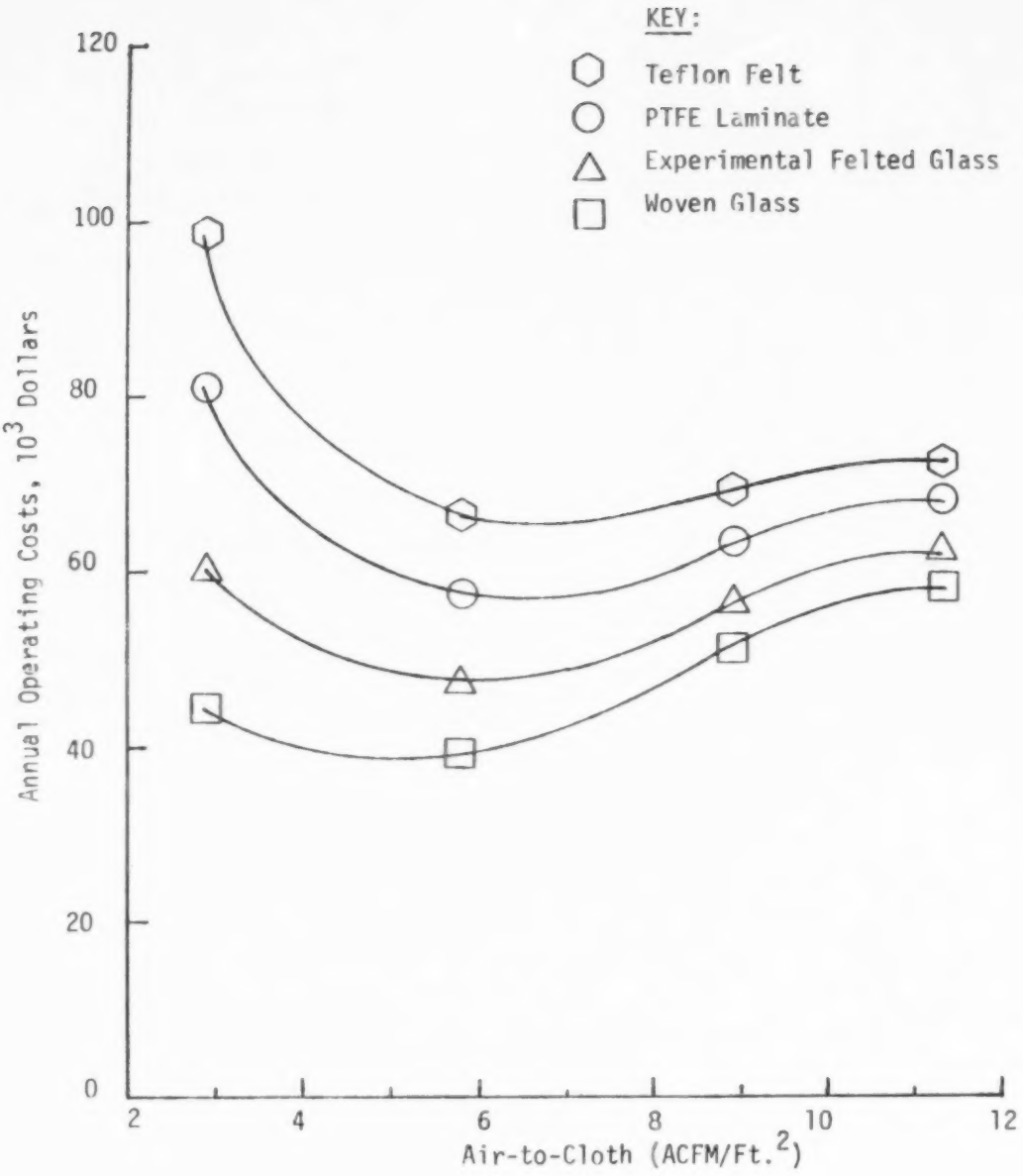

Figure 33

Annual Operating Costs vs. Air-to-Cloth Ratio for All Media Assuming a Four Year Bag Life

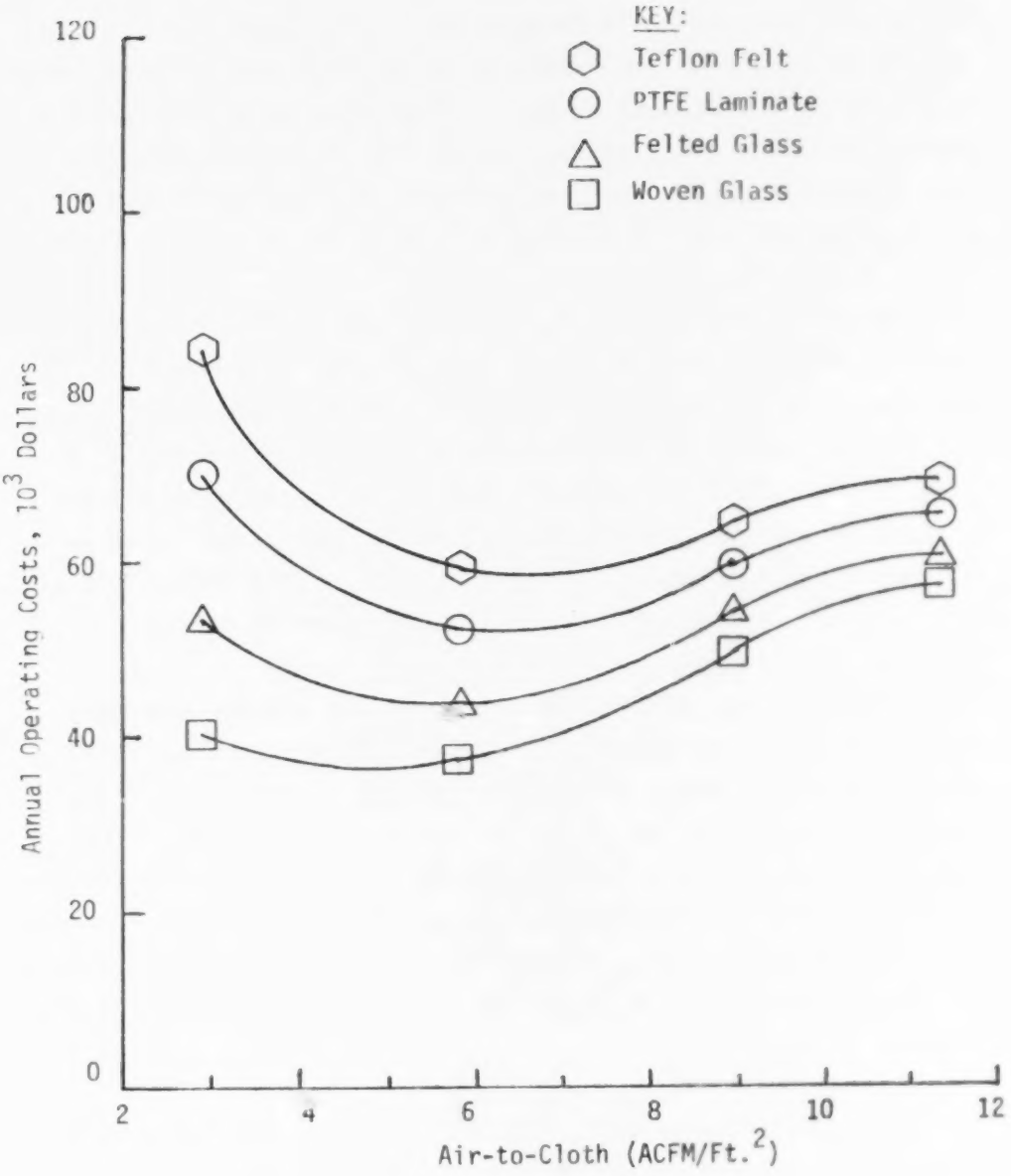

Figure 34

Comparison of Annual Operating Costs vs. Air-to-Cloth Ratio for All Media Assuming a Five Year Bag Life

Examination of Figures 35 through 38 shows that operating costs will depend on the percent bag replacement per year. The tests conducted by Enviro-Systems & Research were not extensive enough timewise to estimate bag life typical of each filter media tested in the NTTC system, but the most economical bag usage can be predicted to some extent. For a bag replacement of 20% to 100% per year, the most economical system in terms of operating costs would employ the woven glass bags with an air-to-cloth ratio of 5.8.

Factors inherent in the NTTC system such as high chloride ion concentrations and acid dew-point problems may cause speedier destruction of one media over another. The woven glass bags with a 5.8 air-to-cloth ratio are generally most reasonable overall; however, if they could not be used, another media with a 5.8 air-to-cloth ratio such as the experimental felted glass fabric with up to 63% annual replacement, PTFE laminate at 39% or the Teflon felt at 30% could all be used with fairly similar operating costs.

The operating costs for the electrostatic precipitator were determined by adding the operating costs of the precipitator itself and the operating costs of the main fan (See Appendix A-8). The maintenance cost used was 3% of the flange-to-flange cost. This value is between average and high for the cost range and was used due to the corrosive elements in the gas stream. The power consumed (112 KVA for the precipitator and total connected load) were actuals. For 98.5% efficiency, the annual operating cost was $37,632 or $0.27/ACFM.

The operating costs for a wet scrubber were calculated as in Appendix A-8 with Edminsten and Bunyard methods. Again, an average to high maintenance cost of $0.05/ACFM was used because of the corrosive nature of the gas stream. Annual operating costs for the wet scrubber were calculated to be $253,539 or $1.81/ACFM.

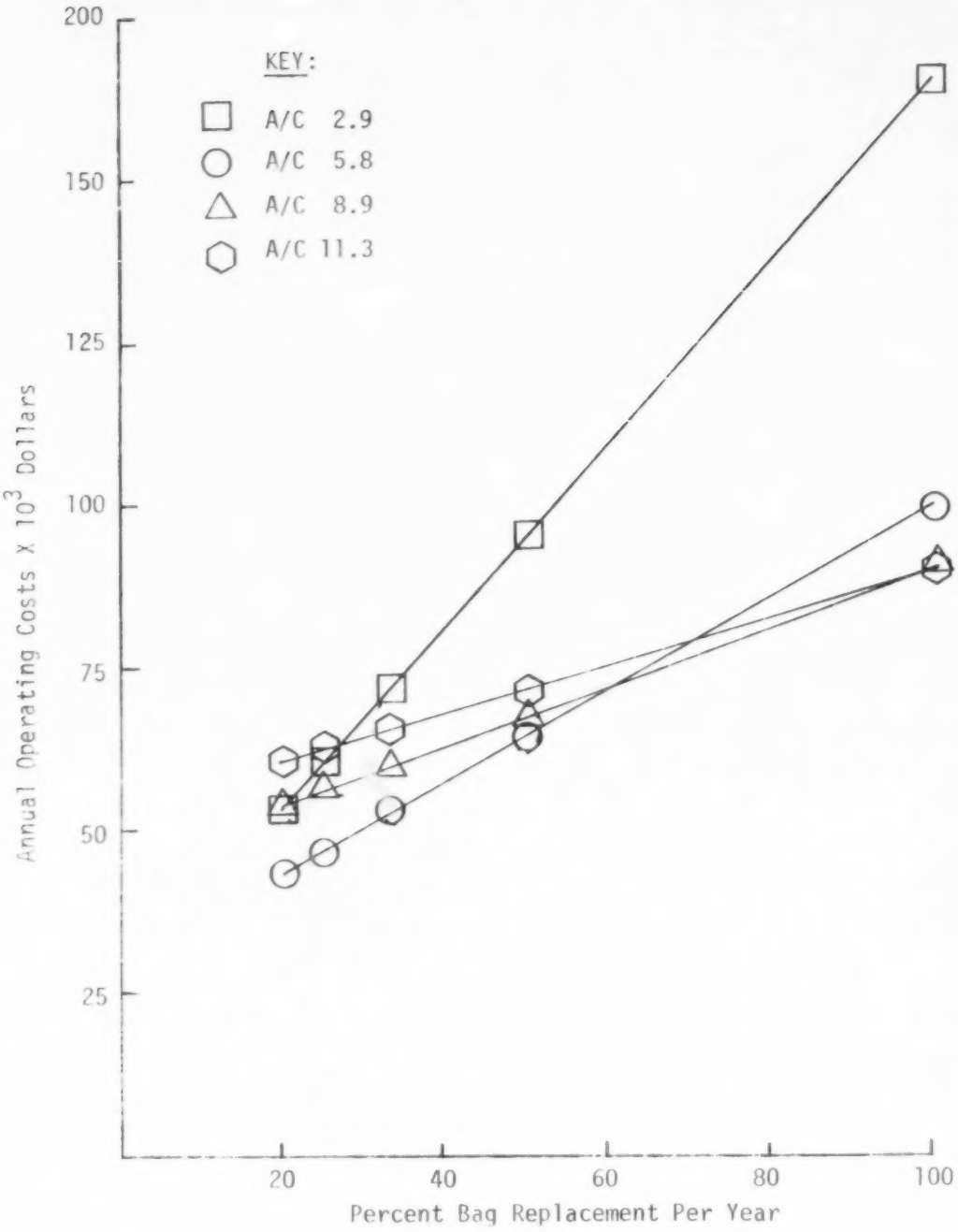

Figure 35

Annual Operating Costs vs. % Bag Replacement Per Year at Different Air-to-Cloth Ratios (Experimental Felted Glass)

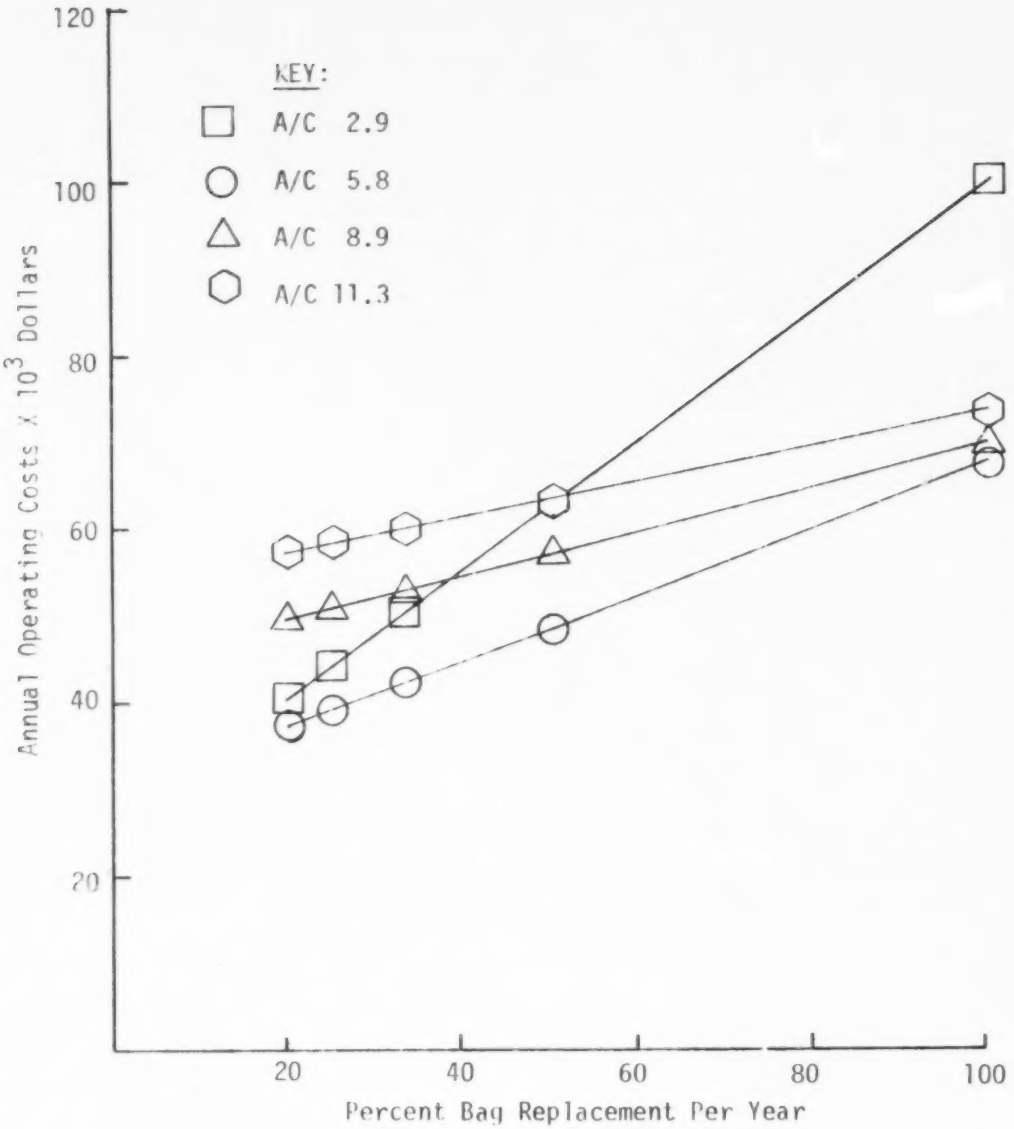

Figure 36

Annual Operating Costs vs. % Bag Replacement Per Year at Different Air-to-Cloth Ratios (Woven Glass)

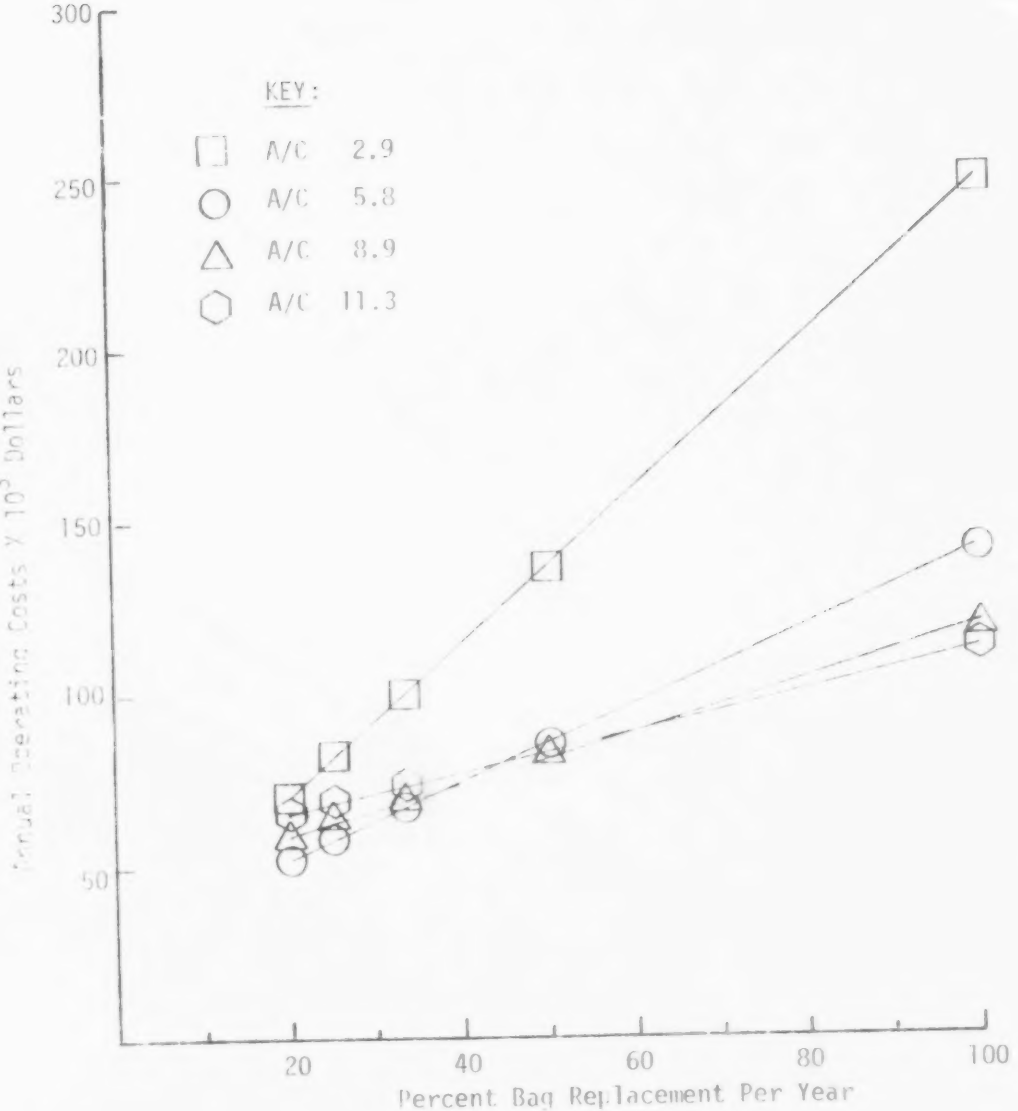

Figure 37

Annual Operating Costs vs. % Bag Replacement Per Year
at Different Air-to-Cloth Ratios (PTFE Laminate)

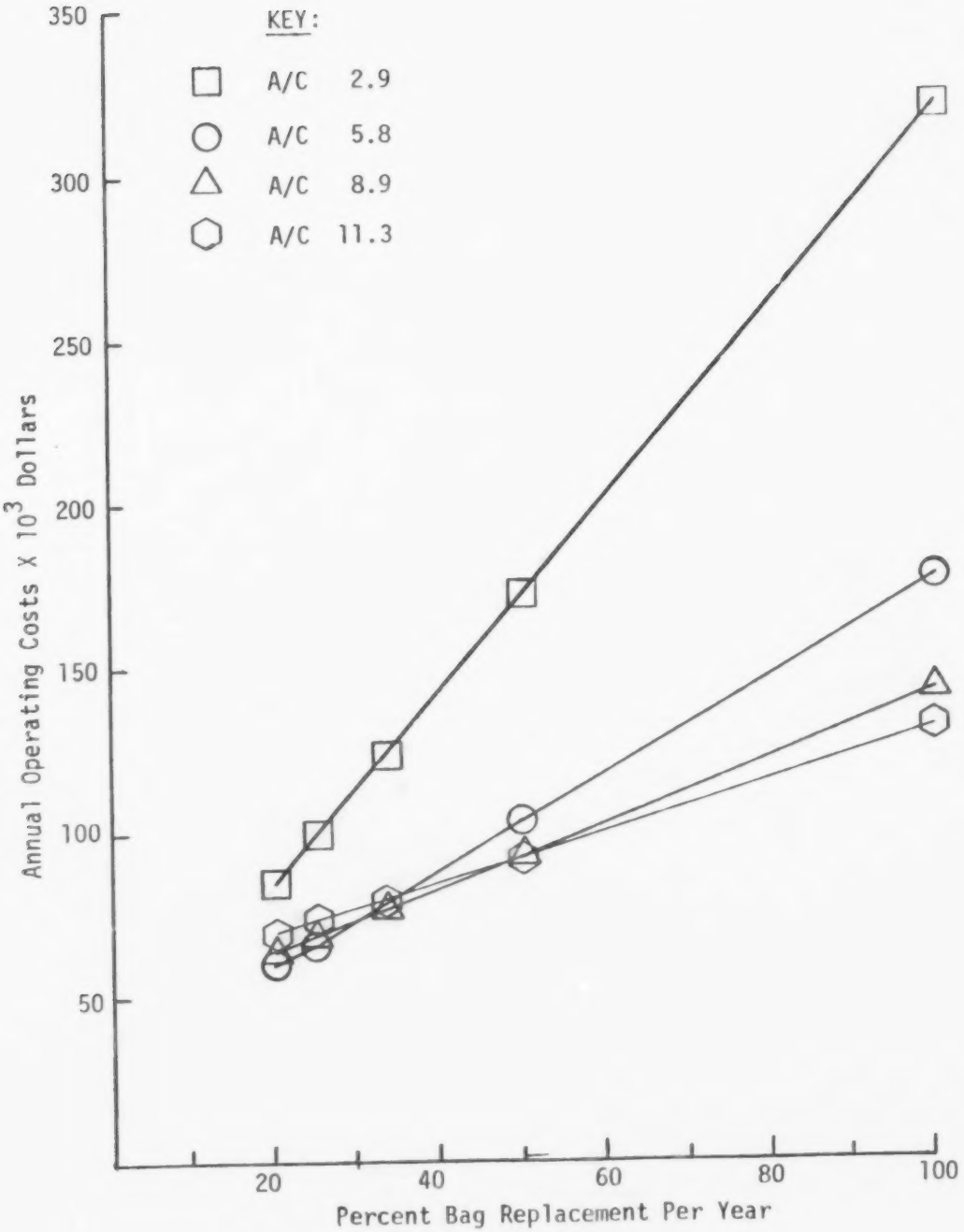

Figure 38

Annual Operating Costs vs. % Bag Replacement Per Year at Different Air-to-Cloth Ratios (Teflon Felt)

A comparison of these three methods, as in Figure 39, shows that the electrostatic precipitator is the most economical and the wet scrubber the least economical with respect to annual operating costs. Of all the bag life and air-to-cloth ratios examined, only two cases would alter this conclusion: First, using Teflon felt with a one-year bag life at an air-to-cloth ratio of 2.9/1, the fabric filtration method would be the most expensive; and second, using woven glass bags with a bag life of five years at an air-to-cloth ratio of 5.8/1 would make fabric filtration a less expensive method than electrostatic precipitation. For the most part, however, electrostatic precipitation is the least expensive method with respect to annual operating costs.

Annualized Costs of Control

The annualized costs -- or total costs of control -- were developed from the preceding installed and annual operating costs using the same calculations in Appendix A-8. The results are shown for each media per year in Figures 40 through 44, and are based on the following assumptions: First, hardware and installation costs were depreciated over fifteen (15) years. Second, the straight line method of depreciation (6 2/3 percent per year) is used. This method has the simplicity of constant annual write-off. Third, other costs called capital charges, which include interest, taxes, insurance and other miscellaneous costs, are assumed equal to the amount of depreciation, or 6 2/3 percent of the initial installed cost. Therefore, depreciation plus these other annual charges amount to 13 1/3% of the installed costs. For easy referral, Table 13 lists all fabric filter data broken down into annualized costs of control. The lowest cost fabric was the woven glass at $0.66/ACFM for an air-to-cloth ratio of 8.9 and a five-year bag life.

The total annualized costs of control for an electrostatic precipitator and a wet scrubber were developed as in Appendix A-8.

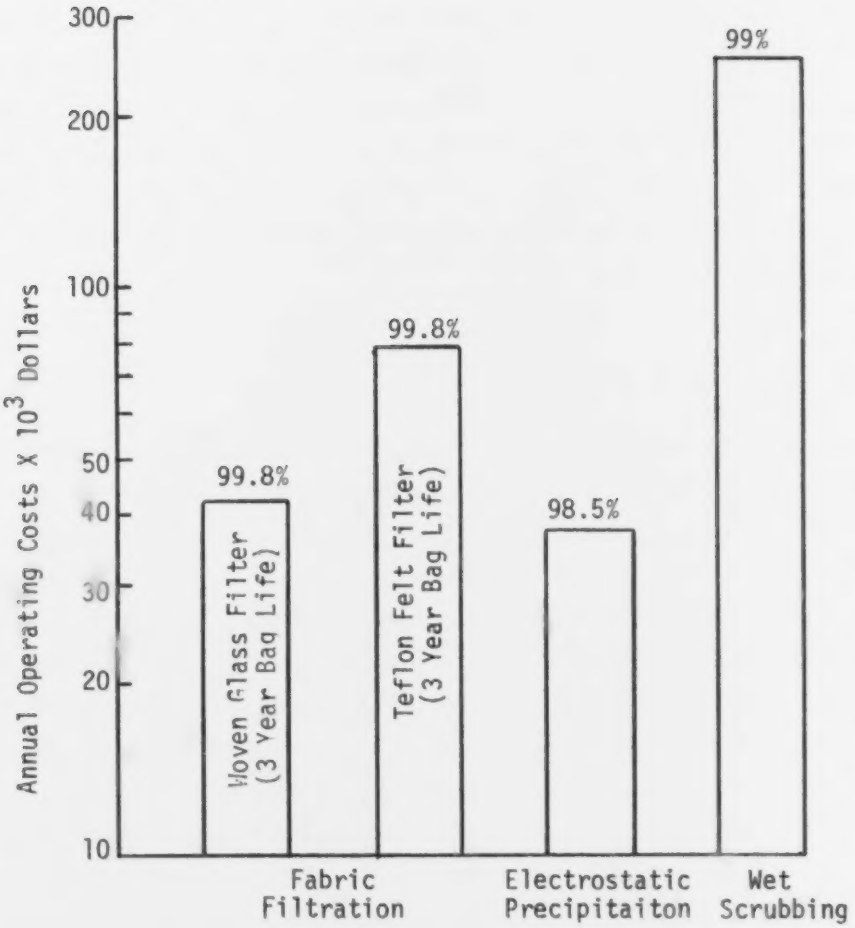

Figure 39

Annual Operating Cost Comparison for Three Air Pollution Control Techniques

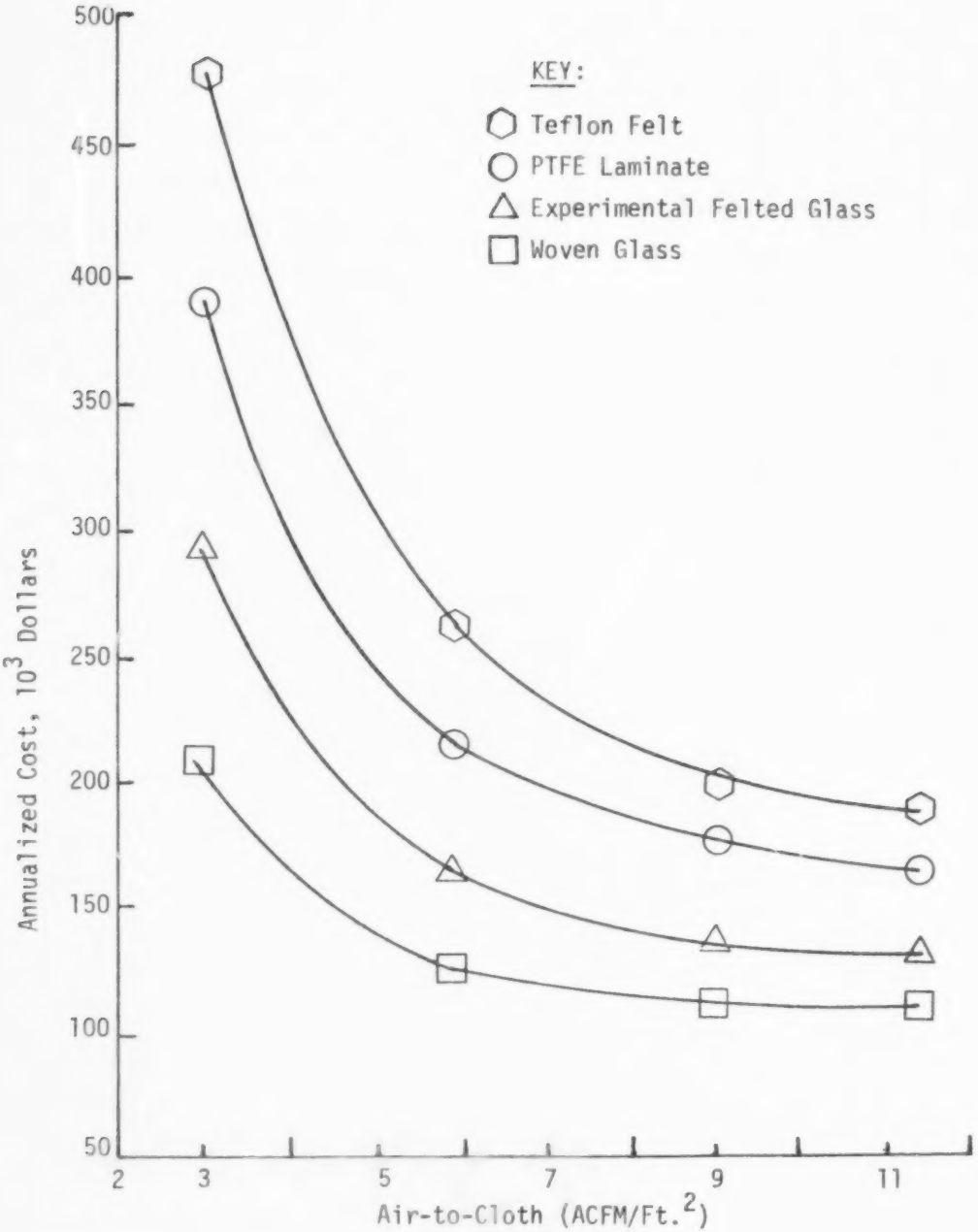

Figure 40

Comparison of Four Media for Annualized Costs vs. Air-to-Cloth Ratio Assuming a One Year Bag Life

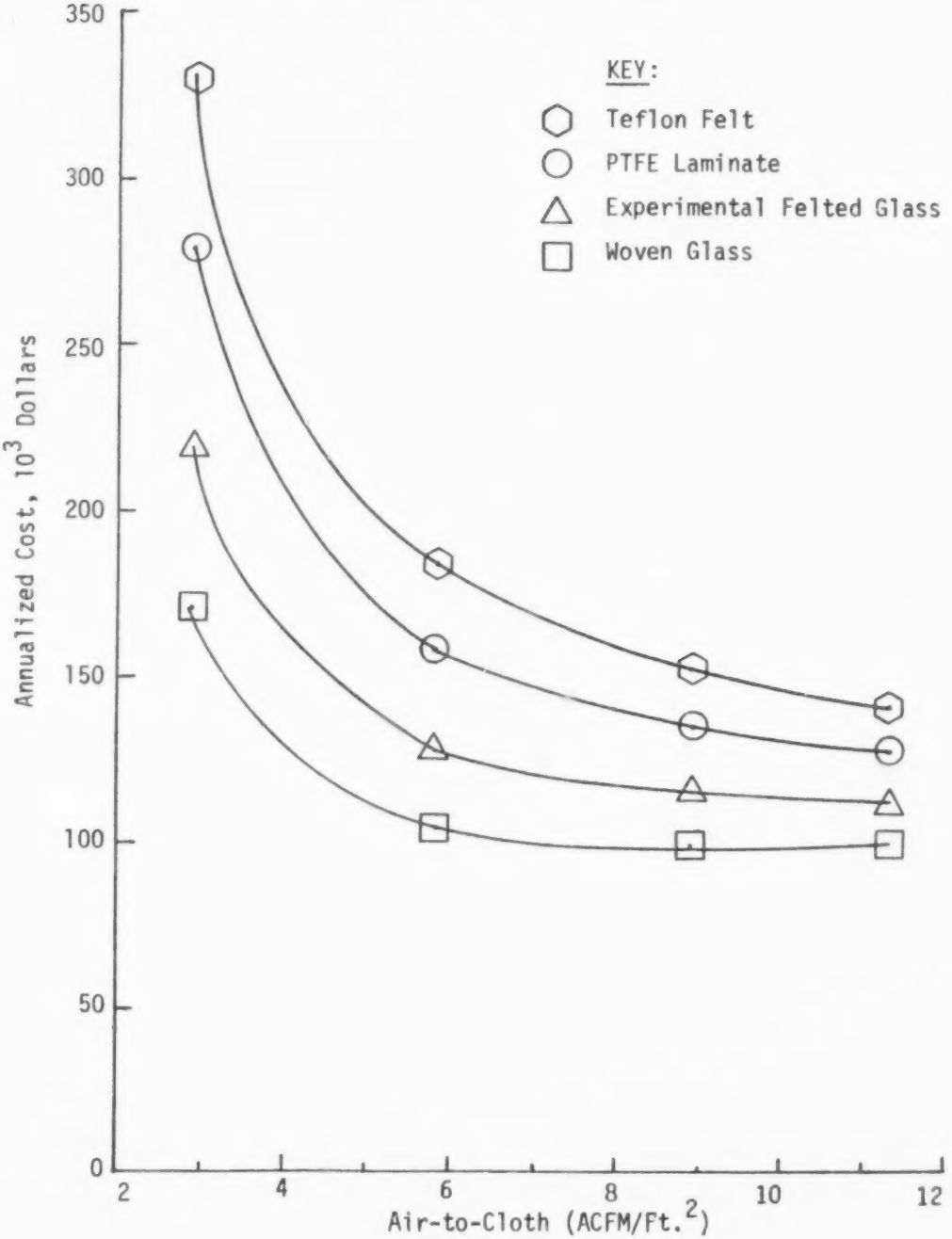

Figure 41

Comparison of Four Media for Annualized Costs vs. Air-to-Cloth Ratio Assuming a Two Year Bag Life

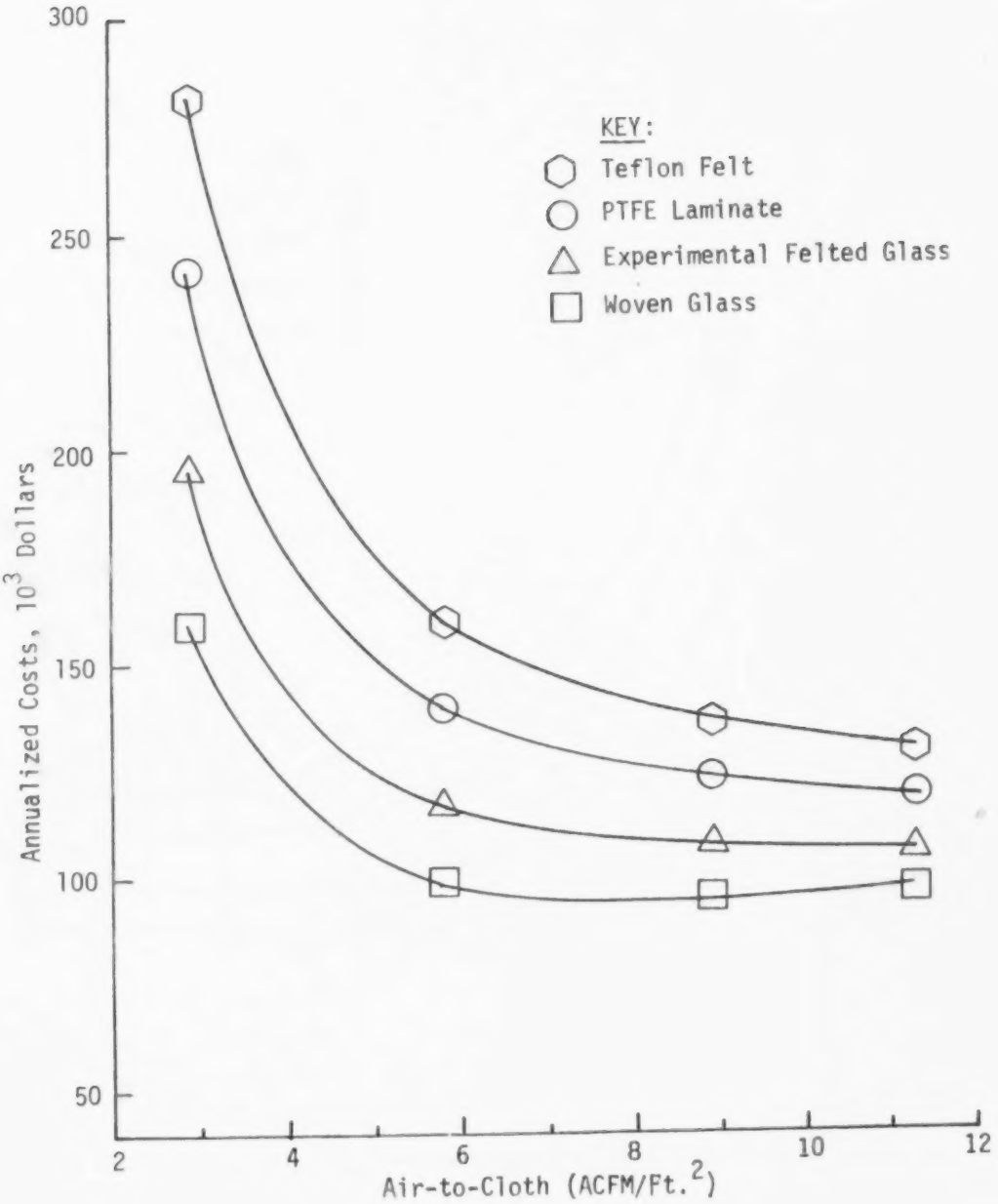

Figure 42

Comparison of Four Media for Annualized Costs vs. Air-to-Cloth Ratio Assuming a Three Year Bag Life

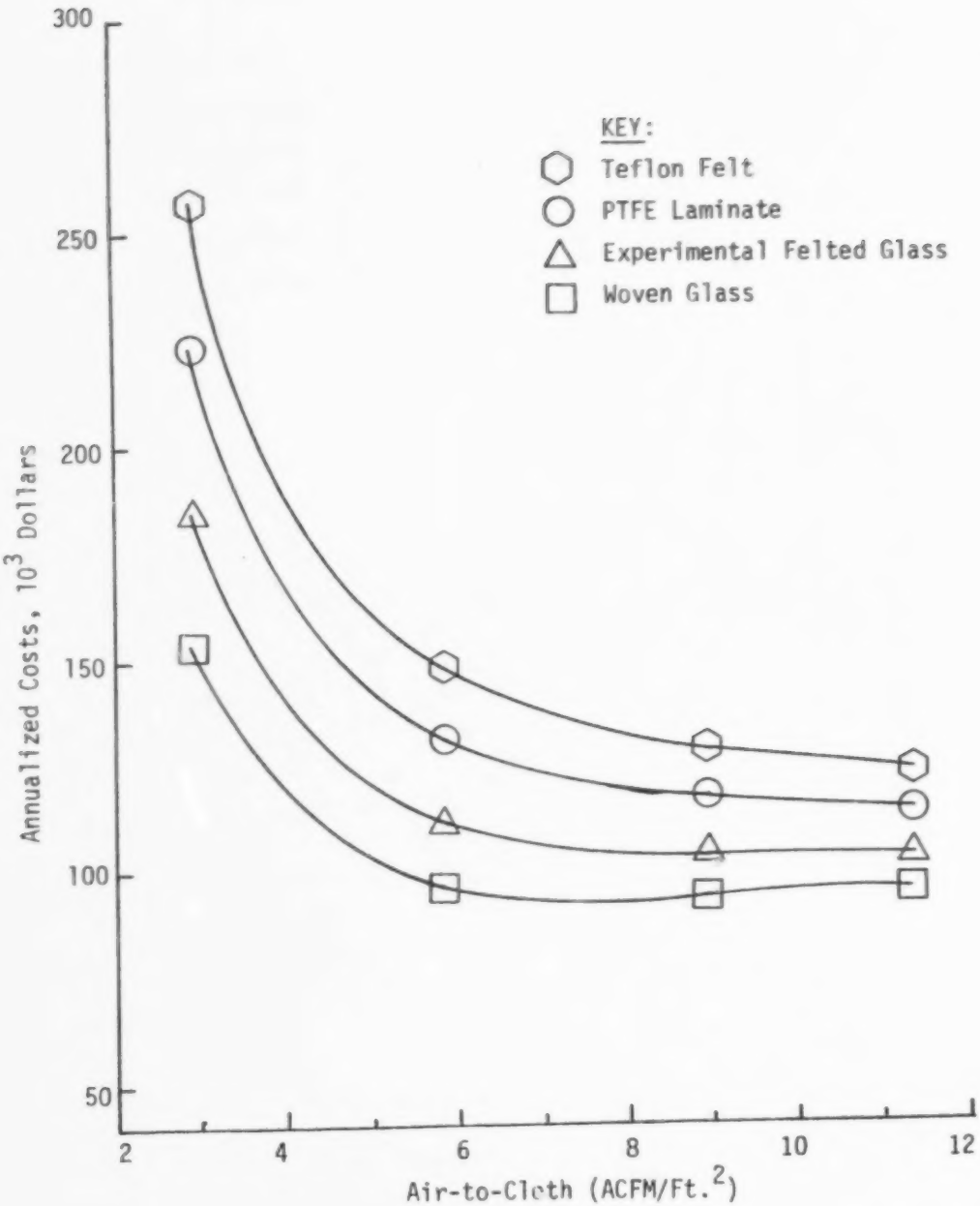

Figure 43

Comparison of Four Media for Annualized Costs vs. Air-to-Cloth Ratio Assuming a Four Year Bag Life

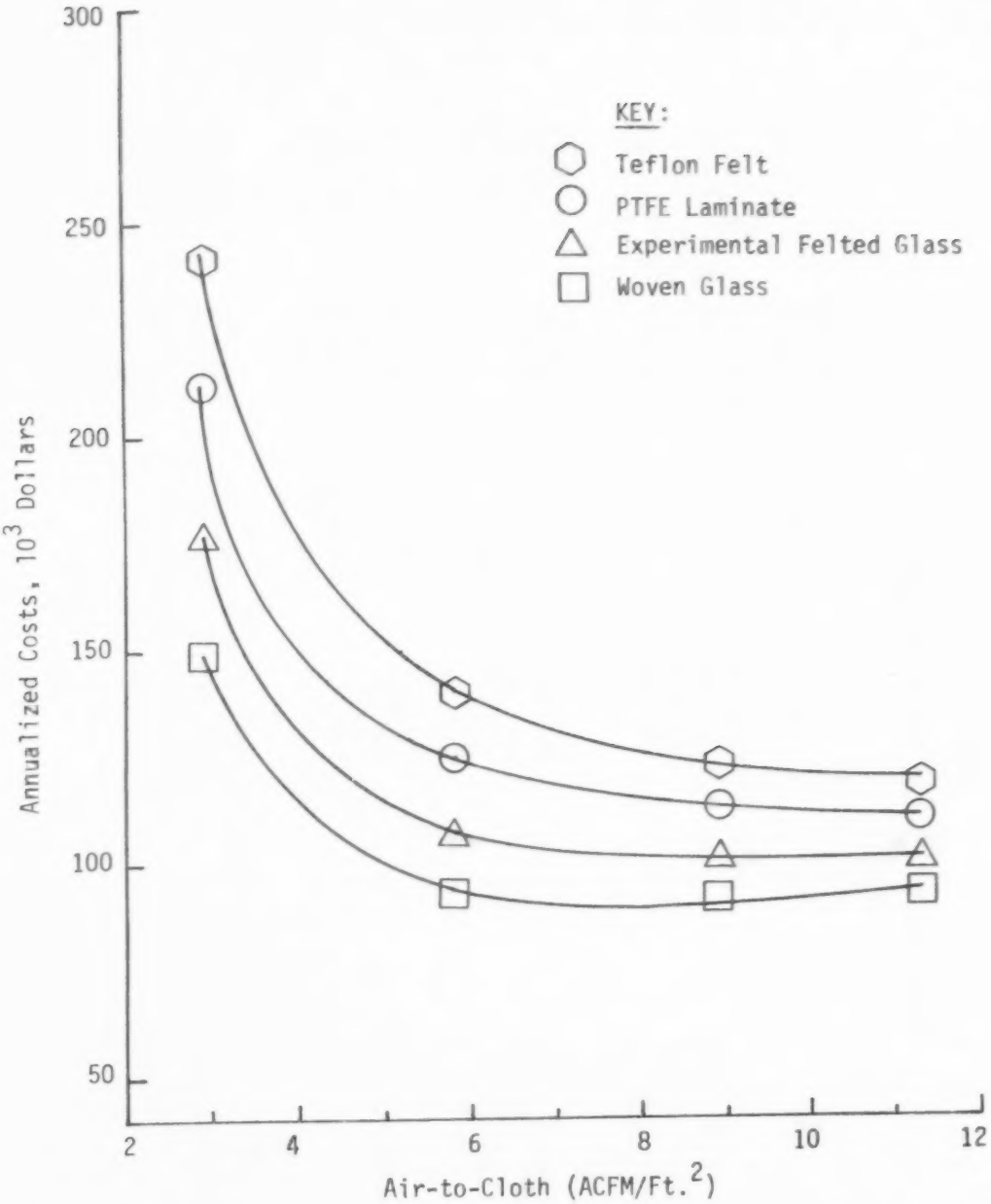

Figure 44

Comparison of Four Media for Annualized Costs vs. Air-to-Cloth Ratio Assuming a Five Year Bag Life

Table 13

Annualized Costs of Control for Fabric Filters

Filter	A/C	Bag Life 1 Year	2 Years	3 Years	4 Years	5 Years
Woven Glass	2.9	$208,838	$171,570	$159,138	$152,950	$149,226
Experimental Felted Glass	2.9	289,085	219,099	195,719	184,099	177,113
PTFE Laminate	2.9	390,243	279,013	241,857	223,391	212,261
Teflon Felt	2.9	477,648	330,760	281,704	257,330	242,644
Woven Glass	5.8	123,237	104,617	98,387	95,293	93,431
Experimental Felted Glass	5.8	163,368	128,368	116,692	110,882	107,382
PTFE Laminate	5.8	213,954	158,332	139,754	130,514	124,956
Teflon Felt	5.8	257,642	184,212	159,684	147,490	140,140
Woven Glass	8.9	111,804	99,386	95,242	93,184	91,938
Experimental Felted Glass	8.9	138,562	115,224	107,440	103,562	101,238
PTFE Laminate	8.9	172,277	135,205	122,815	116,655	112,945
Teflon Felt	8.9	201,407	152,449	136,097	127,977	123,077
Woven Glass	11.3	109,402	99,476	96,158	94,506	93,512
Experimental Felted Glass	11.3	130,806	112,144	105,914	102,820	100,944
PTFE Laminate	11.3	157,789	128,123	118,211	113,283	110,329
Teflon Felt	11.3	181,088	141,927	128,837	122,341	118,421

For a precipitator with an efficiency of 98.5%, the costs are $151,371, or $1.08/ACFM. For a 99% efficient wet scrubber the costs are $347,681, or $2.48/ACFM.

Comparing the annualized costs of control for these methods, as in Figure 45, wet scrubbing is again the most expensive except in the cases of the PTFE laminate and the Teflon felt filters with a one-year bag life at an air-to-cloth ratio of 2.9/1. Electrostatic precipitation is the less expensive method when compared with fabric filtration at an air-to-cloth ratio of 2.9/1. However, at an air-to-cloth ratio of 5.8/1 or greater, fabric filtration with woven glass bags (with bag life of one year or greater) has lower annualized costs than electrostatic precipitation. By examining Table 13, it can be seen that other bags with varying air-to-cloth ratios and bag life will also have lower annualized costs than an electrostatic precipitator at $151,371 per year.

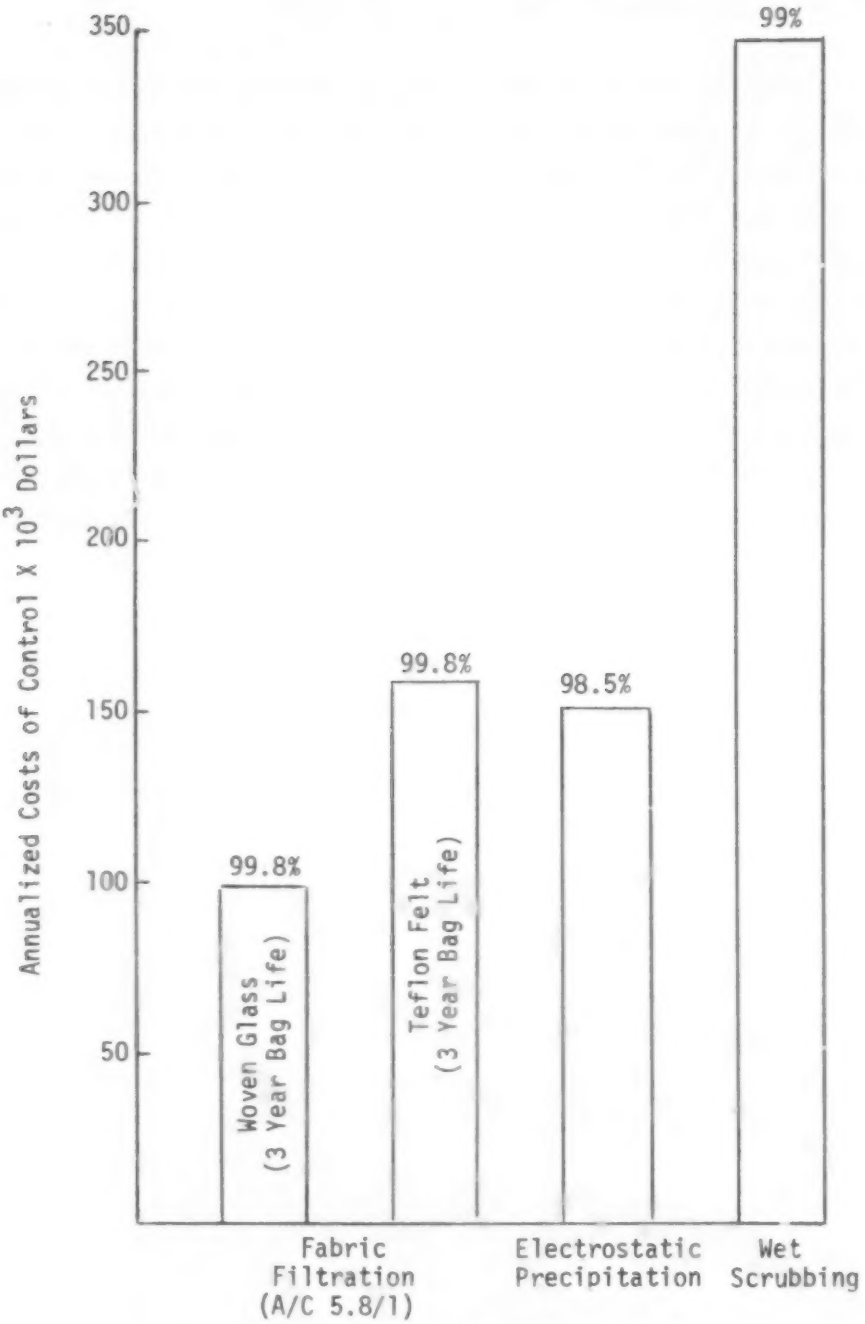

Figure 45

Annualized Cost for the Three Air Pollution Control Techniques

DISCUSSION

The performance of the pilot plant indicated that high levels of dust removal efficiency could be obtained. All three filter medias tested exceeded the dust removal requirements of both the State of Tennessee and the Federal codes.

Dew point excursions and sub-dew point operation prohibited attainment of meaningful pressure drop data. For this reason no conclusions regarding the commercial suitability of pressure drop levels during normal operation were made.

As might be expected, sub-dew point operation resulted in a high degree of corrosion, thus a great deal of maintenance and replacement of mechanical parts were required. This was particularly notable in the case of the cleaning system dampers and the cylinder and valves associated with these dampers.

As shown in the economic analysis, the wet scrubber does not compare well with the electrostatic precipitator or fabric filters in terms of operating and annualized costs. In comparing the electrostatic precipitator with the fabric filter, with respect to capital costs, the fabric filter is lower for all bags considered; with respect to operating costs, the electrostatic precipitator is generally lower.

In terms of annualized costs, the least expensive filter media studied (woven glass, 23 oz.) at an air-to-cloth ratio of 5.8/1 or greater shows a lower annualized cost than the electrostatic precipitator,
case with the most expensive filter media (Teflon) where it turns out the electrostatic precipitator looks economically more attractive except in the cases where Teflon felt can achieve three to five

year bag life for air-to-cloth ratios of 5.8/1 through 8.9/1.

Since this cost analysis shows the electrostatic and fabric filter fairly close to each other, the empirical data showing bag life and operating pressure drop are of critical importance in furthering this analysis and allowing one to determine which of the two generic types is the better dust removal alternative for this particular application.

Appendices

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Appendix A-1

Comparison of Physical Properties

of

New and Exposed Fabrics

Table A-1

Physical Properties

Experimental Felted Glass

	New Fabric	Fabric Exposed at NTTC
Machine Direction breaking strength (lb/inch)	527	452.5
Cross Machine Direction breaking strength (lb/inch)	448	419.5
% Elongation	9.6	9.7
Air Permeability (CFM/Sq. Ft. @ 1/2"H2O)	28	20
Mullen Burst (lb./Sq. inch)	400 + #	400 +

equipment reads up to 400 lb./Sq. inch

Table A-1
(continued)

Woven Glass

Fiber Content	Glass
Weave	3 x 1 twill
Count	46 x 23
Yarn System	2 ply multifilament (warp)
Yarn System	3 ply texturized + 1 ply multifilament (fill)

		Fabric Exposed At NTTC	New Fabric
Weight Ounces/Sq. Yard	As received	28.3	
	Cleaned	22.8	22.5
Permeability CFM/Sq. Ft. @ 1/2 H20	As received	3.9-4.4	
	Cleaned	25.5-27.0	25
Grab Strength	Warp	800	800-850
	Filling	450	440-480
Mullen Burst lbs./sq. inch		820	800+
M. I. T. Flex Cycles,(below 100 considered Flex failure)		10,994	up to 15 % Loss
P. H. Text		5.0	
Ignition Loss		4.4 %	

Table A-1
(continued)

Teflon Woven

Property	XT-0954 Exposed Sample	New XT-0954 Typical
1" Ravel Strip Tensile - ASTM D1682 - WxF	120 x 85	120 x 100
Bursting Strength - ASTM D751 Diaphragm (Mullen)	280 psi	280 psi
Frazier Porosity ASTM D737	30	20-40

The results show no loss of physical properties as a result of exposure to the conditions at Nashville Thermal.

TABLE A-1 (cont.)

PROPERTIES OF TREATED NOMEX® FELT
EXPOSED 4 MONTHS IN INCINERATOR GAS STREAM

	Physical Properties	
	New	4 Mo. Exposure
Basis Weight, oz./yd.^{2}	19.2	20.2
Thickness	78	50
1" Strip Tensiles (MD/XD)		
Breaking Str., lbs./in.	131/100	76/57
Elongation, %	66/77	13/13
Work-to-Break, lbs./in.	54/43.5	6/5
Mullen Burst, lbs./in.^{2}	388	302

Appendix A-2

NTTC Ash:

Procedures for Analysis

and

Results of Analysis

Procedure for Analysis of Ash from Nashville Thermal

1. Dry approximately 300 grams of ash overnight at 70° C.
2. Weigh 5 grams of dried ash and mix with 40 ml distilled water for eight hours.
3. Filter above mixture through a millipore filter.
4. Dry millipore filter and residue overnight at 70° C.
5. Calculate Percent Water Soluble.
6. At the same time that item (2) is initiated, weigh 250 grams of dried ash and mix for eight hours with 2000 ml distilled water.
7. Filter sample on glass fiber filter.
8. Wash with 1000 ml of distilled water and filter again.
9. Repeat item (8).
10. Filter solution from (7), (8), & (9) through millipore filter.
11. Perform following analysis on filtrate:

pH	Potassium
Alkalinity	COD
Hardness	Nitrate
Calcium	Phosphate
Iron	Zinc
Sulfate	Lead
Chloride	Total Dissolved Solids
Sodium	

Table A-2

Analysis of NTTC Ash

January 6, 1977

Sample Designation	Fly Ash	Cinder Ash
Sample Number	3382	3383
% Water Soluble	13.4	1.1
Analysis of Filtrate		
pH	10.5	12.0
Alkalinity mg/1 as $CaCO_3$	50	760
Hardness mg/1 as $CaCO_3$	2038	706
COD mg/1	38	172
Total Dissolved Solids mg/1	9122	1108
Total Phosphate mg/1 as P	0.1	0.35
Sulfates mg/1	1149	37
Calcium, mg/1	843	370
Potassium, mg/1	700	47
Sodium, mg/1	1339	83
Chloride, mg/1	4120	117
Fluorides, mg/1	2.32	1.16
Lead, mg/1	0.31	0.48
Zinc, mg/1	0.04	0.16
Nitrates, mg/1	2.45	1.56
Iron, mg/1	0.06	0.04

Appendix A-3

Experimental Felted Glass Fabric

November 1976 Results

Experimental Felted Glass Fabric
November 1976 Results

Figures A-3a thru A-3c, pressure drop vs. time curves, indicate that the fabric does have some self-cleaning tendencies and will operate at acceptable pressure drop levels for the air-to-cloth ratios studied. These self-cleaning tendencies were not seen in the April tests, due probably to less frequent readings. Another observation is that the pressure drop at lower air-to-cloth ratios remained as low (0.3" W.G.) during testing with no reverse-air cleaning as during reverse-air employment. This is demonstrated in Figure A-3d.

An Andersen sampler was used to obtain in-situ particle size data for the air-to-cloth ratios of 4.2, 6 and 9.4 Inlet flue gas volumes ranged from 1970 ACFM to 2914 ACFM. Test periods lasted up to two (2) hours with the reverse-air fan off. No testing was conducted during periods of boiler upset.

Figure A-3e shows the particle size distribution for air-to-cloth ratios of 4.2, 6 and 9.4. In ascending order of air-to-cloth the percentage of particulate matter less than three (3) microns is 88%, 54% and 47% respectively. From the graph, it appears that bags with the A/C of 4.2 release the smallest percentage of particles larger than three (3) microns. At the inlet, however, 74% of the total particulate entering was larger than three (3) microns.

The mass mean particle diameters at the outlet for A/C ratios of 4.2, 6 and 9.4 are 0.71 micron, 1.98 microns and 3.45 microns respectively, and are smaller than those found in the April tests. Average outlet concentrations and relative cumulative percentages are given in Table A-3. Based on the most current inlet particulate concentrationtion of 0.538 grains/SCFD, the fractional efficiencies of the experimental felted glass fabric in the Enviro-Systems & Research baghouse in increasing A/C ratios are 98.6%, 99.8% and 99.2%.

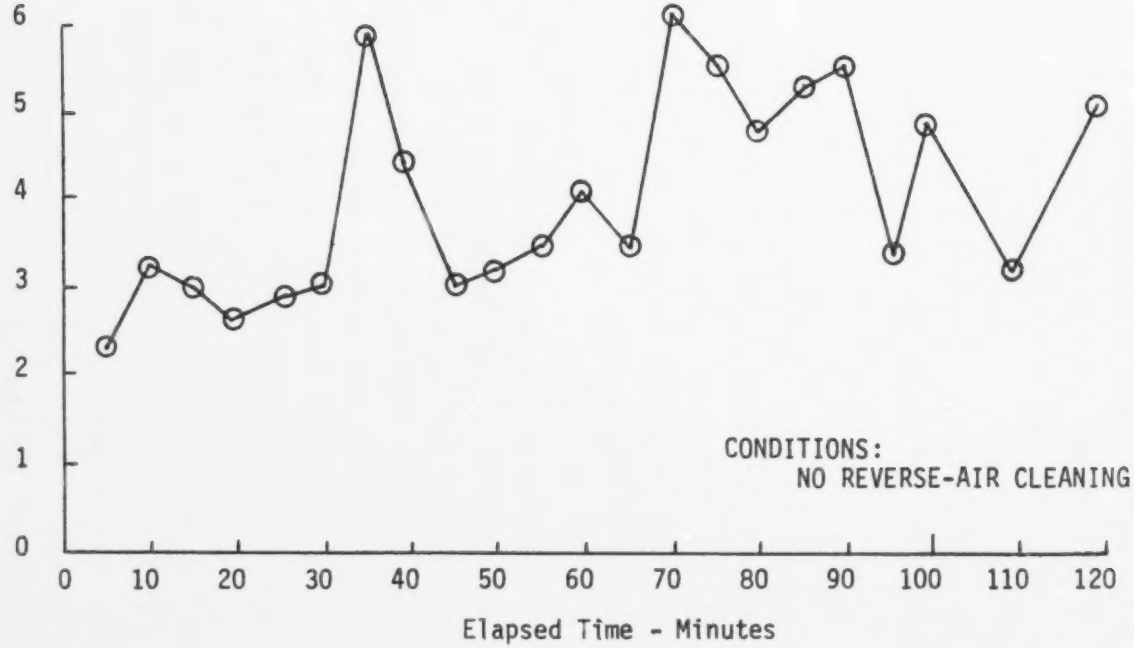

Figure A-3a

Experimental Felted Glass Bags -- Pressure Drop vs. Time for A/C - 6.04/1

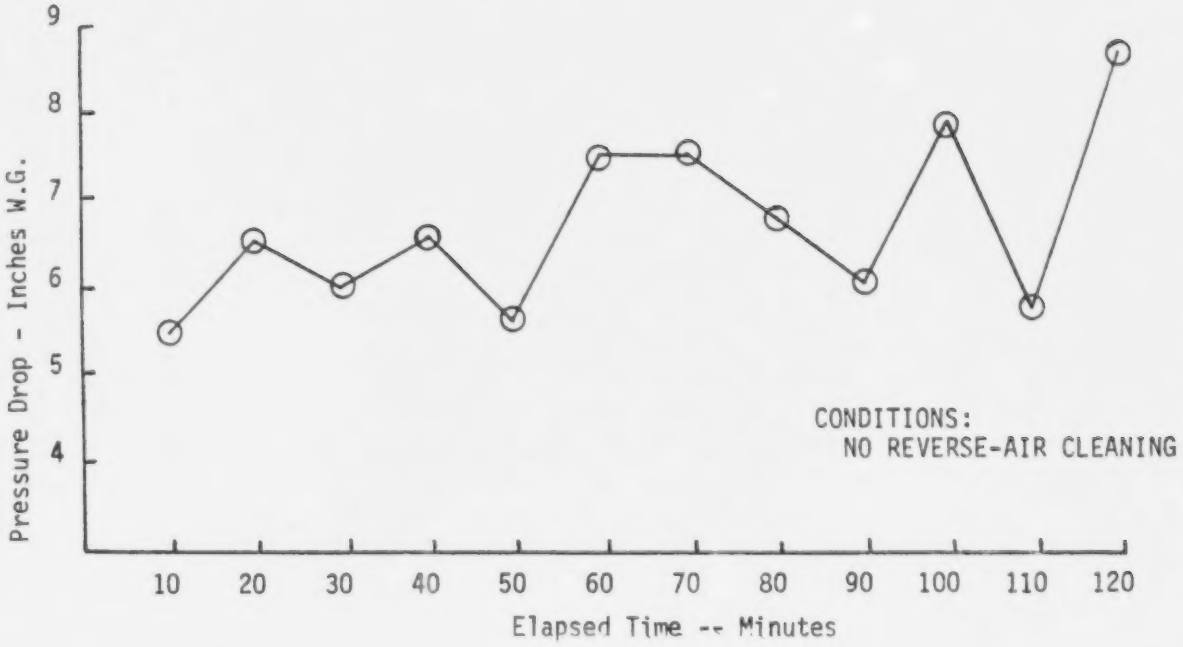

Figure A-3b

Experimental Felted Glass Bags -- Pressure Drop vs. Time for A/C = 9.4/1

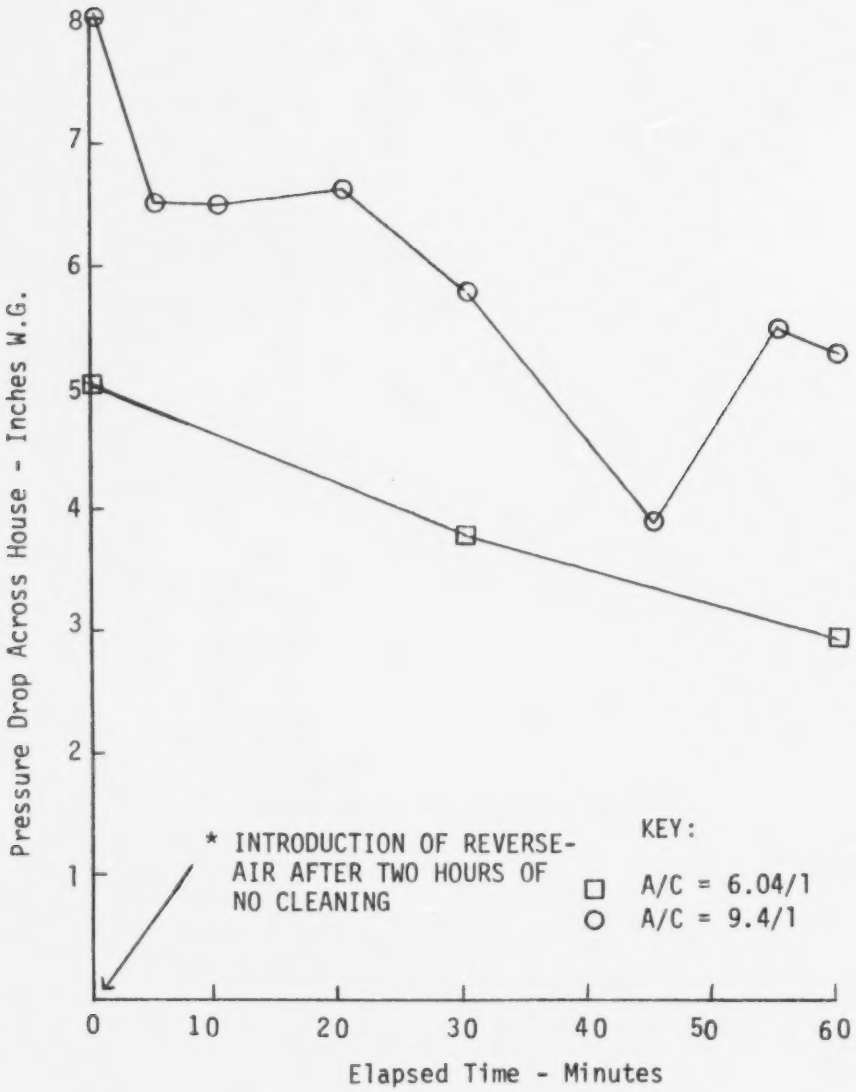

Figure A-3c

Pressure Drop vs. Time for Reverse-Air Cleaning of Experimental Felted Glass Bags

(The first point is the introduction of reverse-air cleaning after two hours of no cleaning. The cleaning cycle consits of seven seconds of cleaning each cell every 120 seconds.)

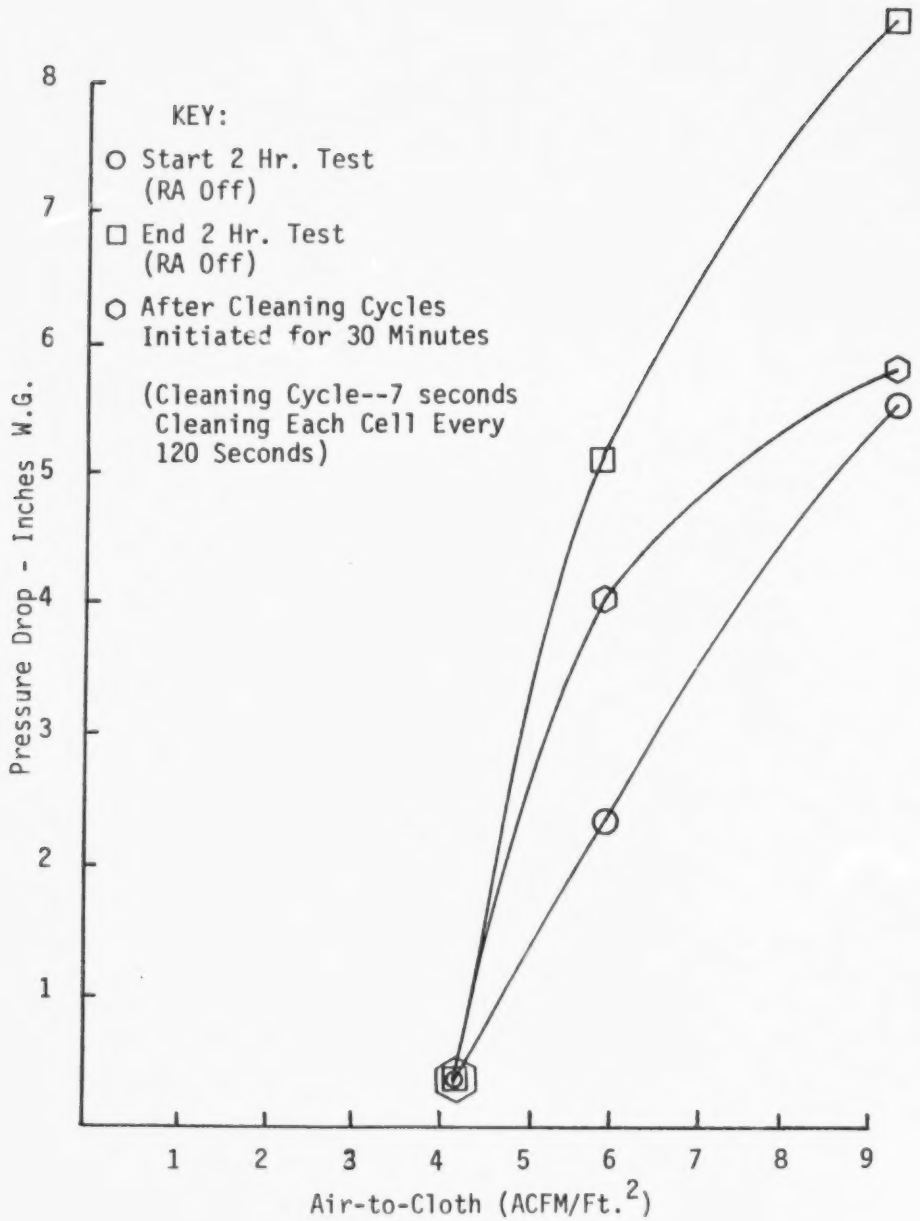

Figure A-3d

Pressure Drop vs. Air-to-Cloth Ratio for Experimental Felted Glass Bags

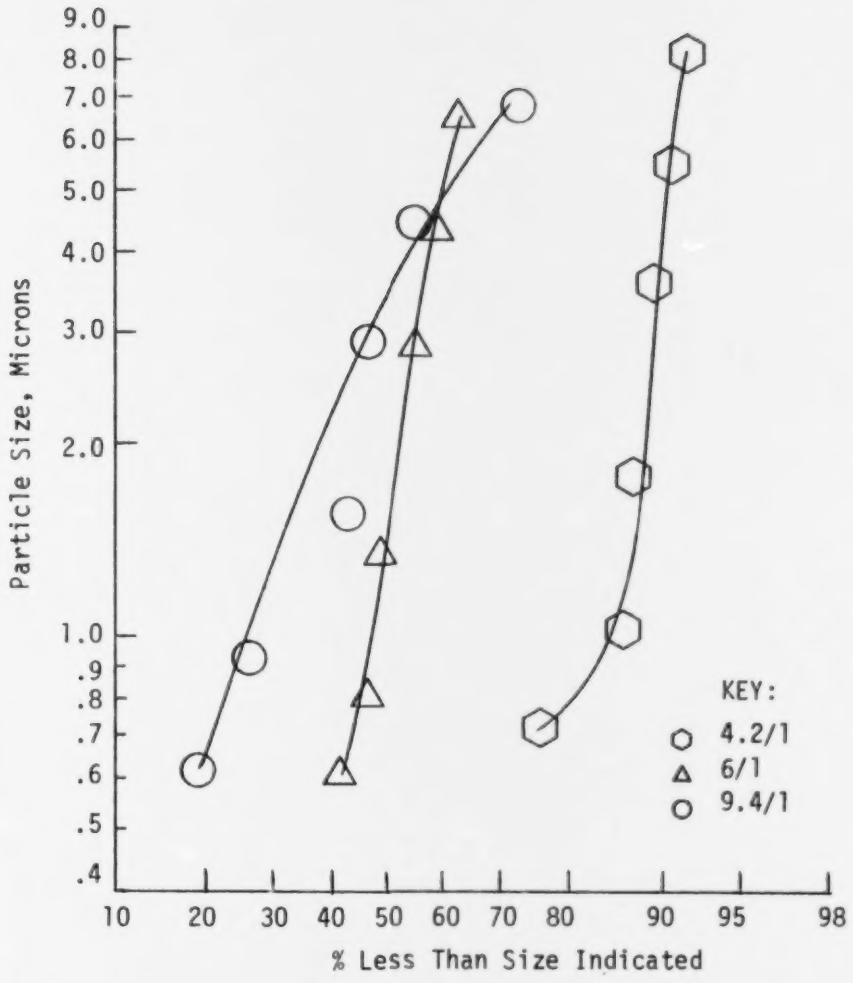

Figure A-3e

Outlet Particle Size Distribution

Experimental Felted Glass Bags

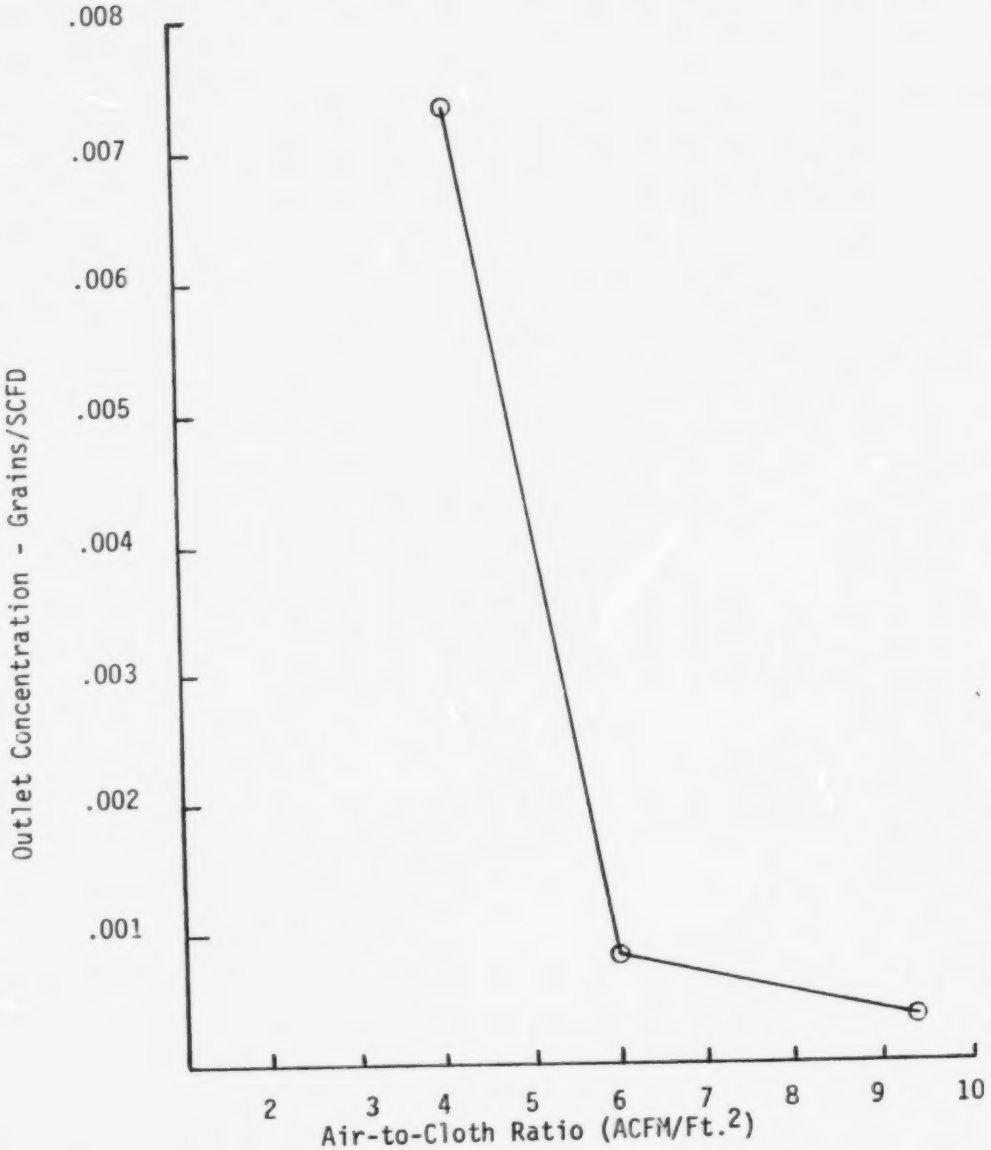

Figure A-3f

Outlet Concentration vs. Air-to-Cloth Ratio for Experimental Felted Glass Bags - Nov. Test

Table A-3

Outlet Concentration and Cumulative %

Experimental Felted Glass Bags

Air-to-Cloth 4.2/1			Air-to-Cloth 6/1			Air-to-Cloth 9.4/1		
Avg. (1) Part. Diam. Microns	Avg. (2) Outlet Conc. gr/SCFD	Cum % (3)	Avg. Part. Diam. Microns	Avg. Outlet Conc. gr/SCFD	Cum %	Avg. Part. Diam. Microns	Avg. Outlet Conc. gr/SCFD	Cum %
11.1	0.000649	100.00%	8.8	0.000340	100.00%	9.1	0.000117	100.00%
7.5	0.000145	91.16	6.0	0.0000359	61.58	6.2	0.0000717	71.3
5.1	0.000125	89.19	4.1	0.0000384	57.48	4.2	0.0000345	53.61
3.3	0.000149	87.49	2.6	0.0000564	53.09	2.7	0.0000173	45.1
1.7	0.0000565	85.46	1.3	0.0000205	46.64	1.4	0.0000619	40.84
1.0	0.000785	84.69	0.8	0.0000384	44.3	0.9	0.0000272	25.6
0.71	0.00191	74.01	0.6	0.0000513	39.9	0.6	0.0000173	18.9
< 0.71	0.00353	48.03	<0.6	0.000298	34.05	<0.6	0.0000593	14.6
TOTAL	0.0073495			0.0008751			0.000404	

(1) Corrected for Stack Temperature
(2) gr/SCFD - Grains Per Standard Cubic Foot Dry (Standard - 70 F, 29.92" Hg)
(3) Percent of Total Outlet Concentration Less Than Size Indicated

Appendix A-4

Particle Size Distribution Data

Brinks Impactor - Inlet

Anderson Impactor - Outlet

Table A-4

Brinks Inlet Particle Size Distribution

3/22/77

	Run 1		Run 2	
	D_{50} Lower Size Limit (Microns)	% Cumulative	D_{50} Lower Size Limit (Microns)	% Cumulative
Precutter	19.23	100.00	20.09	34.04
Stage 1	11.69	24.53	12.22	30.68
Stage 2	6.64	21.63	6.95	19.27
Stage 3	3.95	16.76	4.13	16.69
Stage 4	2.71	12.04	2.84	14.98
Stage 5	1.46	11.58	1.53	12.08
Stage 6	0.95	8.69	1.00	9.17

Table A-4

Particle Size Distribution for Andersen Sets

Experimental Felted Glass

And. Run #	A/C Ratio	Particle Size Distribution (Microns) Stage # #1	#2	#3	#4	#5	#6	#7	#8	#9
RA 4-11	3.2	8.5	5.7	3.9	2.5	1.2	0.73	0.46	0.20	0.20
RA 8	3.2	9.5	6.5	4.3	2.9	1.4	0.83	0.59	--	--
RA 6	6.4	7.8	5.3	3.6	2.3	1.2	0.7	0.5	0.31	0.31
RA 7	6.4	9.6	6.5	4.4	2.9	1.4	0.86	0.59	0.33	0.33
RA 3	8.7	9.4	6.7	4.5	3.0	1.4	0.9	0.59	0.37	0.37
RA 5	8.7	9.4	6.7	4.5	3.0	1.4	--	--	--	--
TOTAL		54.2	37.4	25.2	16.6	8.0	4.02	2.78	1.21	1.30
AVG		9.33	6.23	4.2	2.77	1.33	.804	.556	.3025	.325

PTFE Laminate

RA 2-11	4.4	8.4	5.7	3.9	2.5	1.2	0.77	0.52	--	--
RA 1-11	4.4	8.4	5.7	3.9	2.5	1.2	0.77	0.52	0.19	0.19
RA 1	4.8	8.4	5.6	3.9	2.5	1.2	--	0.5	--	--
RA 3-11	5.4	8.4	5.7	3.9	2.5	1.2	0.77	0.52	0.49	0.49
RA 4-9	6	8.4	5.7	3.9	2.5	1.2	0.77	0.26	--	--
RA 5-9	6	8.4	5.7	3.9	2.5	1.2	0.77	--	0.56	0.56
TOTAL		50.4	34.1	23.4	15.0	7.2	3.85	2.32	1.24	1.24
AVG		8.4	5.7	3.9	2.5	1.2	0.77	0.46	0.41	.41

Table A-4 (continued)

Woven Glass

Particle Size Distribution (Microns)

And. Run #	A/C Ratio	Stage # #1	#2	#3	#4	#5	#6	#7	#8	#9
RA 8-11	2.75	8.8	6.0	4.1	2.6	1.3	--	--	--	--
RA 2	2.75	8.0	5.5	3.7	2.4	1.2	0.8	0.5	0.5	
RA 4	4.1	8.6	5.8	4.0	2.6	1.3	0.8	0.5	--	--
RA 5-11	4.2	8.0	5.5	3.7	2.4	1.2	0.8	0.5	0.18	0.18
RA 6-11	6.7	9.8	6.7	4.5	2.9	1.5	0.9	0.6	0.16	0.16
RA 7-11	6.7	9.9	6.7	4.6	2.9	1.5	0.9	0.6	--	--
TOTAL		53.1	36.2	24.6	15.8	8.0	4.2	2.7	0.34	0.34
AVG		8.85	6.033	4.1	2.63	1.33	.84	.54	0.17	0.17

Appendix A-5

Fractional Loading Data

Table A-5

Fractional Loading For Andersen Sets****

Experimental Felted Glass

	Air-to-Cloth 3.2/1			Air-to-Cloth 6.4/1			Air-to-Cloth 8.7/1		
And. Run#	RA 4-11*	RA 8**	AVG	RA 6	RA 7	AVG	RA 3	RA 5***	AVG
Stage #1	.0001303	.0002365	.0001834	.0000864	.0002676	.0001770	.0007071	.0003176	.0005394
Stage #2	.0000519	.0000794	.0000657	.0000160	.0000843	.0000502	.0002528	.0002416	.0002472
Stage #3	.0000402	.0000379	.0000391	.0000267	.0000917	.0000592	.0001985	.0002339	.0002162
Stage #4	.0000593	.0000325	.0000459	.0000203	.0000211	.0000207	.0001250	.0001208	.0001229
Stage #5	.0000350	.0001137	.0000744	.0000160	.0000147	.0000154	.0000735	.0000963	.0000849
Stage #6	.0000445	.0000126	.0000286	.0000256	.0000348	.0000302	.0000720	.0000673	.0000697
Stage #7	.0000434	0	.0000434	.0000107	.0000202	.0000155	.0000338	0	.0000338
Stage #8	.0000455	0	.0000455	.0000128	.0000183	.0000156	.0000485	0	.0000485
Stage #9	.0000582	.0000382	.0000482	.0000309	.0000678	.0000494	.0001073	0	.0001073
TOTAL	.0005083	.0005508	.0005742	.0002454	.0006205	.0004332	.0016185	.0011315	.0014699

* Weighings of the first four substrates based on weight after heavy rust-like particles (not impacted on the substrate, rather loose on foil) were removed; last five substrates did not have this problem.

** Weighings of first six substrates also dealt with removal of rust-like particles; last three substrates weights were average of before and after loose particle removal.

*** Last three substrates contained rust particles and were wet at weighing, so were not included as representative results (.81mg, 32.97mg and 78.75mg were weights)

**** Grains/SCFD

Table A-5 (continued)

Fractional Loading For Andersen Sets *****

Woven Glass

	Air-to-Cloth =2.75			Air-to-Cloth =4.2			Air-to-Cloth =6.7		
And. Run#	RA 2*	RA 8-11**	AVG	RA 4***	RA 5-11	AVG	RA 6-11	RA 7-11****	AVG
Stage #1	.0004359	.00002532	.0003446	.0001281	.0002592	.0001936	.0001100	.0000538	.0000819
Stage #2	.0001894	.00001052	.0001473	.0000534	.0000759	.0000647	.0000722	.0000107	.0000415
Stage #3	.0000665	.00005970	.0000631	.0000240	.0000832	.0000536	.0000591	.0000230	.0000411
Stage #4	.0000794	.00004550	.0000625	.0000373	.0000864	.0000618	.0000673	.0000338	.0000506
Stage #5	.0000579	.00002560	.0000417	.0000400	.0000801	.0000601	.0000575	.0000338	.0000456
Stage #6	.0000493	.00003690	.0000431	.0000160	.0000957	.0000558	.0001150	.0000507	.0000828
Stage #7	.0000515	0	.0000515	.0000080	.0000884	.0000482	.0001314	.0000954	.0001134
Stage #8	.0000493	0	.0000493	0	.0001009	.0001009	.0001823	.0004342	.0002527
Stage #9	0	0	0	0	.0000843	.0000843	.0002563	0	.0025630
TOTAL	.0009792	.0005264	.0008031	.0003068	.0009541	.0007230	.0010511	.0006243	.0009659

* 110.88mg recorded for substrate 9--not representative, so not used.

** Recorded weights for substrates 7, 8, & 9 were 0.93, 6.65, 56.97 mg--these were not deemed representative and were not used.

*** Recorded weights for substrates 8 & 9 are 0.01 and 214.63 mg--these were not deemed representative and were not used.

**** Even after three hours of oven drying substrates 8 (2.1 mg) and 9 (450.05 mg) were not deemed representative and were not used.

***** Grains/SCFD

Table A-5 (continued)

Fractional Loading For Andersen Sets****

PTFE Laminate

	Air-to-Cloth = 4.20			A/C = 5.4	A/C = 4.8	Air-to-Cloth = 6		
And. Run#	RA 1-11	RA 2-11*	AVG	RA 3-11	RA 1**	RA 4-9	RA 5-9***	AVG
Stage #1	.0002768	.0000751	.0001760	.0006280	.0000463	.0001683	.0001722	.0001703
Stage #2	.0000359	.0000111	.0000235	.0000961	.0000628	.0000721	.0000488	.0000605
Stage #3	.0000858	.0000166	.0000512	.0002230	.0000194	.0000400	.0000976	.0000688
Stage #4	.0000387	.0000361	.0000374	.0000564	.0000269	.0000587	.0000334	.0000461
Stage #5	.0000498	.0000834	.0000666	.0000423	.0000284	.0000347	.0000154	.0000251
Stage #6	.0000913	.0000361	.0000637	.0000333	0	.0000614	.0000077	.0000346
Stage #7	.0000581	0	.0000581	.0000179	.0000209	.0000374	0	.0000374
Stage #8	.0000276	.0000166	.0000221	.0000179	0	.0000374	.0000051	.0000213
Stage #9	.0000304	.0000500	.0000402	.0000230	.0000119	.0000552	.0000411	.0000482
TOTAL	.0006945	.0003250	.0005388	.0067270	.0002166	.0005652	.0004213	.0005123

* Zero weight gain was recorded for 7th substrate

** Substrates six and eight lost weight; therefore, no average of substrates was computed.

*** Slightly negative numbers were recorded for substrate six; these losses could be due to loss of part of the foil wrappings for the filters or perhaps the filter was slightly damp at time of weighing.

**** Grains/SCFD

Appendix A-6

Compilation of Andersen Run Data

Table A-6

Andersen Runs (NTT)

Date of Run	Type of Bag	A/C	Temp. Stack	Grains/ ACF	Grains/ DSCF	Mass Efficiency (.538)*	Mass Efficiency (.329)* *
3/7/77	PTFE Laminate	6.3/1	70 F.	0.000553	0.000565	99.89	99.82
3/8/77	PTFE Laminate	6.3/1	70 F.	0.000417	0.000422	99.92	99.87
3/9/77	PTFE Laminate	4.4/1	70 F.	0.000670	0.000694	99.87	99.79
3/9/77	PTFE Laminate	4.4/1	70 F.	0.000315	0.000326	99.94	99.90
3/18/77	PTFE Laminate	5.4/1	62 F.	0.000625	0.000673	99.87	99.80
3/19/77	PTFE Laminate	4.8/1	50 F.	0.000212	0.000217	99.96	99.93
3/22/77	Woven Glass	4.1/1	118 F.	0.000311	0.000299	99.94	99.91
3/23/77	Woven Glass	2.75/1	165 F.	0.000525	0.000526	99.90	99.84
3/23/77	Woven Glass	2.75/1	167 F.	0.000916	0.000960	99.82	99.71
3/24/77	Woven Glass	6.7/1	150 F.	0.000108	0.001050	99.80	99.68
3/24/77	Woven Glass	4.2/1	165 F.	0.000938	0.000955	99.82	99.71
3/24/77	Woven Glass	6.7/1	149 F.	0.000615	0.000625	99.88	99.81
3/31/77	Experimental Felted Glass	8.7/1	149 F.	0.001590	0.001620	99.69	99.51
4/1/77	Experimental Felted Glass	6.4/1	115 F.	0.000237	0.000245	99.95	99.93
4/1/77	Experimental Felted Glass	6.4/1	114 F.	0.000640	0.000641	99.88	99.81
4/1/77	Experimental Felted Glass	3.2/1	85 F.	0.000656	0.000671	99.88	99.80
4/1/77	Experimental Felted Glass	3.2/1	87 F.	0.000610	0.000595	99.89	99.82

*Inlet loading in grains/DSCF at old port

**Inlet loading in grains/DSCF at new port

Appendix A-7

Statistical Analysis

of

Outlet Loading and Air-to-Cloth Ratios

Statistical Analysis

A statistical analysis was conducted to determine if there was significant relationship between outlet loading and air-to-cloth (A/C) ratio (velocity through the filtering media). This analysis was done in four parts. First, an overall correlation coefficient between grain loading bodies and A/C was developed. Second, a correlation coefficient between grain loading bodies and A/C at separate filtering media was determined. Third, separate correlation coeficients between grain loading and A/C for the two hour and four-hour data were calculated. Lastly, a fitting of a model relating grain loading to A/C with filtering media included in the model or a qualitative model was created.

Overall Correlation Coefficient

This was the calculation of the correlation coefficient between air-to-cloth (A/C) and loading, using grains/SCFD, ignoring filtering media and length of run. The correlation coefficient is 0.34096 which is significant at the 0.18 level. Although it could be argued that 0.18 is close to being statistically significant, this correlation is fairly inconclusive. It simply means that there is little linear association between A/C and grain loading across the other variables. This does not indicate a low level of confidence in the data, merely a lack of clear association between the variable A/C and loading.

Correlation at the Separate Filtering Media

The correlation for the PTFE laminate fabric is 0.1463. Since it would be significant at the 0.782 level, it clearly shows no linier association. These calculations were based primarily on two (2) hour runs, so the PTFE laminate fabric should not be condemned completely.

The woven glass fabric yielded a correlation of 0.1989 which, again, is not significant.

The felted glass media gave a correlation of 0.56954, the highest experienced although the statistical significance is only 0.3162. The low significance is probably due to the small sample size (N=5). The felted glass runs were all four hour runs, however, and this could account for the seemingly better data for the felted glass media.

All of these variables could have been studied independently of each other with an efficient experiment design.

Model Fittings

A model was fitted to see if outlet grain loading was predictable or a function of A/C and the filter medium. It was hampered by the prevalence of two hour runs. A comparison of predicted and observed grain loading values indicates how well the model fits and thus how well filter media and A/C explain grain loading. Table A-7 shows that in some cases the results are good while in others they are not.

Table A-7

Comparison of Predicted and Observed Grain Loading Values

Observation	Observed Value	Predicted Value	Residual
1	0.00056500	0.00056440	-0.00000140
2	0.00042200	0.00056440	-0.00014440
3	0.00069400	0.00041274	0.00028126
4	0.00032600	0.00041274	-0.00008674
5	0.00067300	0.00049362	0.00017938
6	0.00021700	0.00044509	-0.00022809
7	0.00029900	0.00070079	-0.00040179
8	0.00052600	0.00059161	-0.00006561
9	0.00096000	0.00059161	0.00036839
10	0.00105000	0.00091106	0.0013894
11	0.00095500	0.00070887	0.00024613
12	0.00062500	0.00091106	-0.00028606
13	0.00162000	0.00100673	0.00061327
14	0.0024500	0.00082072	-0.00057572
15	0.00064100	0.00082072	-0.00017972
16	0.00067100	0.00056192	0.00010908
17	0.00059500	0.00056192	0.00003308

Appendix A-8

Sample Cost Calculations

for

Fabric Filters

Electrostatic Precipitators

Wet Scrubbers

Appendix A-8

Fabric Filter

Operating and Annualized Costs

Sample Calculations

Formula for calculating theoretical operating and annualized cost of control were taken from: Edminsten, N.G. and Bunyard, F.L., "A Systematic Procedure for Determining the Cost of Controlling Particulate Emissions from Industrial Sources", JAPCA V20 N7, p. 446, July 1970.

I. Fabric Filter Operating Cost:

Case - Teflon Felt at A/C = 5.8/1

$$G = S \frac{0.7457}{6356E} PHK + M$$

Where: G = Theoretical annual cost for operation and maintenance

S = Design capacity, acfm

P = Pressure drop, inches of water

E = Fan efficiency, assumed to be 60% (expressed as 0.60)

0.7457 - A constant, 1 horsepower = .7457 kilowatt

H = Annual operating time, 6240 hours (24 hours/day x 5 days/week x 52 weeks/year = 6240 hours/year)

K = Power costs, $/KWH

M = Maintenance cost, $/ACFM (based on 25% bag replacement per year)

Sample Calculations
(continued)

In this case:

S=140.000 acfm

P*=7 inches of water

E=60%

H=6,240 hours

K=$0.0250/KWH

M=(number of bags in house x 25% replacement rate x cost per bag) S

Assuming a 60% fan efficiency reduces the above equation for G to:

$$G=S\ (195.5 \times 10^{-6}\ PHK + M)$$

Substituting the figures above yields:

$$G=140,000\ (195.5 \times 10^{-6} \times 7 \times 6240 \times .0250 + .2623)$$

$$= 140,000\ (.2135 + .2623)$$

$$=140,000\ (.4758)$$

$$=66,612$$

* Assumes 5.5 inches for the baghouse, 1.5 inches for the inlet duct, etc.

II. Total annualized cost of control is equal to the annual operating cost plus annualized capital cost.

Annualized Capital Cost = 0.133 x Installed Costs

Assumptions:

1. Purchase and installation costs are depreciated over fifteen (15) years.
2. The straight line method of depreciation (6 2/3% per year) is used.
3. Other costs called capital costs are assumed to be equal

3.cont. to the amount of depreciation. Therefore, depreciation plus other capital charges amount to 13 1/3 percent of the initial capital costs of the equipment.

In this case: Teflon Felt at A/C = 5.8

Total annualized cost of control = .133 x Installed Costs + Operating costs

= .133 x $608,104 + $66,612

= 80,878 + 66,612

= $147,490

APPENDIX A-8 (continued)

ELECTROSTATIC PRECIPITATOR

Operating and Annualized Cost Calculations

Formula for calculating theoretical operating and annualized cost of control were taken from: Edminsten, N. G. and Bunyard, F. L., "A Systematic Procedure for Determining the Cost of Controlling Particulate Emmissions from Industrial Sources", JAPCA V20 N7, p. 446. July 1970.

1. Electrostatic Precipitator Operating Cost:

$$G = S\ (JHK + M)$$

Where,

G=Theoretical Annual Operating Cost

S=Design Capacity, ACFM

J*=Power Required, Kilowatts/ACFM

H=Annual Operating Time, 6240 Hours

K=Power Costs, $/KWH

M=Maintenance Costs, $/ACFM

*Does not include power for main fan.

at 98.5% Efficiency

$$G = 140{,}000\ (.0008)\ (6240)\ (0.025) + .083$$

$$= 140{,}000\ (0.1248 + 0.083)$$

$$= 140{,}000\ (0.2078)$$

$$= \$29{,}092$$

Appendix A-8

WET SCRUBBERS

Operating and Annualized Cost Calculations

Formula for calculating theoretical operating and annualizedcost of control were taken from: Edminsten, N.G. and Bunyard, F.L., "A Systematic Procedure for Determining the Cost of Controlling Particulate Emissions from Industrial Sources," Journal of the Air Pollution Control Association, Vol. 20, No. 7, P. 446, July 1970.

I. Wet Scrubber Operating Cost:

$$G = S\ 0.7457\ HK\ (Z + (Qh/1980)) + WHL + M$$

Where:
- G = theoretical annual operating cost
- S = design capacity, ACFM
- 0.7457 = constant (1 horsepower=0.7457 KW)
- H = annual operating time, 6240 hours
- K = power costs, $/KWH
- Z = contact power (or, total power input required for collection efficiency) horsepower/ACFM
- Q = liquor circulation, gallons/ACFM
- h = physical height liquor is pumped in' circulation system, in feet
- W = make-up liquor consumption, gallons/ACFM
- L = liquor cost, $/ACFM
- M = maintenance cost, $/ACFM

For this application:

- S = 140,000 ACFM
- H = 6240 hrs.
- K = $0.025/KWH
- Z^* = 0.015 HP/ACFM (for high efficiency)
- Q^* = 0.008 gal/ACFM
- h^* = 30 feet
- W^* = 5×10^{-4} gal/hr ACFM

L^{*}= \$0.67 x 10^{-3}/gal/hr (value inflated from Edminsten & Bunyard value at 6%/year)

M^{*}= \$0.05/ACFM (typical to high value)

* Values for a typical system from tables in the Edminsten and Bunyard article.

$$G = 140{,}000 \quad 0.7457(6240)(0.025)\left(0.015 + \left(0.\frac{008 \times 30}{1980}\right)\right) + (5 \times 10^{-4})(6240)(0.67 \times 10^{-3}) + 0.05$$

$$G = 140{,}000\ (1.7589 + 0.0021 + 0.05)$$

$$G = 140{,}000\ (1.811)$$

G = \$253,539 or \$1.81/ACFM

II. Wet Scrubber Annualized Costs

Total annualized cost of control is equal to the annual operating cost plus the annualized capital cost.

Annualized Capital Cost* = 0.133 x Installed Cost

Total Annualized Cost = Annualized Capital Cost + Annual Operating Cost

at 99% efficiency, Total Annualized Cost =

(0.133 x \$707,840) + \$253,359

= \$94,143 + \$253,359

= \$347,681 or \$2.48/ACFM

*See fabric filter case for annualized capital cost assumptions.